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ECONOMIC IMPACT OF THE SELENIUM EFFLUENT STANDARD IN ILLINOIS (R76-21)

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ECONOMIC IMPACT OF THE

SELENIUM

EFFLUENT STANDARD IN ILLINOIS (R76-21)

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NOTE

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Opinion of the Economic Technical Advisory Committee
of the Illinois Institute for Environmental Quality

The Economic Technical Advisory Committee has reviewed the economic impact study IIEQ Document No. 77/34, entitled Economic Impact of the Selenium Effluent Standard in Illinois. The Committee finds the report to be generally responsive to the requirements of Section 6 of the Environmental Protection Act and recommends that it be forwarded to the Pollution Control Board so that the public economic impact hearings may be held in connection with proposed regulation R76-21, EFFLUENT STANDARDS REVISIONS, which seeks to amend rule 408 of Chapter 4, Water Pollution Regulations. Cognizance should be taken of the high selenium content of high sulfur fuels and possible increases of selenium effluent discharges in the future.

ECONOMIC IMPACT OF THE SELENIUM EFFLUENT STANDARD

IN ILLINOIS (R76-21)

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Chapter 1

INTRODUCTION

In 1971, the Illinois Pollution Control Board adopted effluent standards to maintain and protect the water quality within the state. According to Rule 408 of Chapter 3 of the Water Pollution Regulations, 22 pollutants are limited to specific concentrations in effluent discharges. On November 2, 1976, the IIEQ submitted a proposal to the Pollution Control Board to delete the effluent standard for selenium from Rule 408. This proposal was based on a study and recommendation by the Illinois Effluent Standards Advisory Group (1976). The IESAG concluded that "there are major uncertainties associated with defining either reliable technology or associated economics for selenium control" (P. 20). The recommendation is that "selenium be deleted as a parameter to be regulated under Rule 408, and that it be regulated only under the Illinois Water Quality Standards and the U.S EPA Effluent Limitations Guidelines" (P. 20).

This report attempts to evaluate:

1. the natural occurrence of selenium;
2. the levels, trends and sources of selenium in surface waters and effluent discharges;
3. the impact of selenium on environmental quality, including biological quality and human health;
4. the effects of possible changes in selenium effluent discharges on the overall environmental quality;
5. and the costs and benefits of regulation versus deregulation.

The information contained in this report should be useful in the decision-making process regarding the selenium effluent standard in Illinois.

Chapter 2

EXECUTIVE SUMMARY

Selenium is a chemically versatile metalloid with properties similar to those of sulfur. Materials having selenium as an essential element are rare; most selenium occurs as a replacement for sulfur in sulfur-bearing materials. As such, selenium is a ubiquitous, although seldom abundant, constituent of rocks, soils, waters, the atmosphere and a wide variety of industrial products and wastes.

Among common natural materials, selenium tends to be relatively enriched in shales, fossil fuels, some soils and certain types of vegetation. Illinois does not contain amounts of such materials at concentrations sufficient to produce detectable background levels of selenium in other than a few streams. Such low concentrations of selenium as do occur in most Illinois stream waters are probably related more to regional combustion of coal and solid wastes, and resultant cycling of selenium through the atmosphere, than to in-basin natural activities.

Selenium is used in a wide variety of industrial processes and has the potential for appearing in many types of effluent. However, this potential is only rarely met; selenium has been detected in less than 2% of all IEPA effluent samples for which it has been analyzed. Among categories of effluent dischargers, only the petroleum refining industry and its subsidiary, the elemental-sulfur recovery industry, have significant records of seleniferous effluent.

Biological and health effects of seleniferous waters are greatly confused by the dual nutrient and toxicant behaviors exhibited by the element. Selenium has been shown to be an essential nutrient for many plants and animals and is probably also an essential nutrient in humans; it has also

been shown to be a toxicant in plants, animals and man. Problems associated with this ambivalent behavior are compounded by limited knowledge of the role(s) played by selenium in metabolism, and by limited knowledge of the threshold concentrations which separate nutrient/toxicant conditions.

Present Illinois standards limit selenium concentrations in general use, restricted use, and effluent waters at 1.0 mg/l, and in water withdrawn for public water supply at 0.01 mg/l. Except for the effluent limitation, these standards are in general agreement with those employed by other states and appear to be adequate to protect both health and environment. The proposed elimination of the Rule 408 effluent standard would remove the selenium restriction on dischargers so long as they do not cause a violation of water quality standards (Rule 402). Imposition of the U.S. EPA Effluent Limitation Guidelines would have practically no effect since selenium is only covered for industries or situations not present in Illinois.

In general, selenium standards have been violated with lesser frequency in Illinois waters than have been the standards for any other regulated substance. No analysis from the ambient water quality monitoring network has ever had a selenium concentration exceeding the 1.0 mg/l standard, and only five analyses have exceeded the .01 mg/l standard. Only a single effluent sample has exceeded the 1.0 mg/l effluent standard.

Detectable levels of selenium have been regularly recorded at only a single IEPA ambient water quality monitoring station, located on Sugar Creek-South. This station is downstream from the effluent outfall which also has both the highest recorded and most consistent record of seleniferous discharges. Although water quality on Sugar Creek-South is generally poor, the poor quality can not necessarily be attributed to its selenium concentrations.

Only a few treatment processes can remove selenium from wastewaters effectively. None of these are conventional processes. At present, there are no known treatment systems employed by any discharger in Illinois which are specifically designed to treat for selenium.

Because of the lack of violations of selenium standards, the principal economic impact of the proposed amendment to the regulation will be the saving to dischargers of the cost of analyzing water samples for selenium ($20.00 per sample at private laboratories). The IEPA will continue to check for selenium as part of routine water quality monitoring.

The proposed amendment will, therefore, have no impact on the people of Illinois as regards: cost of goods and services; the availability of goods and services; and the availability of employment.

There will be no known impact of the amendment on agriculture, including: the cost of food; the availability of food; or the availability of employment.

Likewise, there will be no impact on local government, especially as regards local taxes, local services, and effects on local community expansion.

Finally, the small savings from reduced monitoring will have little impact on commerce and industry. Given their relative insignificance, they should not affect: prices, industrial expansion in Illinois; availability of adequate supplies of energy; or the ability to attract new industry.

Chapter 3

OCCURRENCES OF SELENIUM, INORGANIC

3.1 Introduction

Selenium is a comparatively rare element; it ranks about 70th in total abundance among all elements, approximately equal in absolute quantity to gold and bromine (Waitkins et al, 1942). Although seldom abundant, selenium is widely distributed in rocks, soils, sea water, groundwater, and the atmosphere, from which it may enter surface waters by natural processes of solution/leaching/deposition. Selenium also has a wide range of industrial applications, which serve as a potential source of anthropogenically-derived selenium and seleniferous wastes.

3.2 General Chemistry

Selenium occupies a position among the Group VIb elements on the periodic table, along with oxygen, sulfur, tellurium, and polonium. The elements of this group display increasing metallic properties with increasing atomic weight. Selenium, with an atomic weight of 34, occupies a medial position within the group, and hence exhibits properties of both a metal and a non-metal.

Among the common elements, selenium is most similar in chemical properties to its fellow Group VIb element, sulfur, and is most abundant in materials which contain large amounts of this element. However, its larger ionic radius ($Se^{=}/S^{=}$=1.10; Se^{+6}/S^{+6}=1.12), more metallic behavior, and tendency to form stronger bonds with oxygen, preclude it from many of the roles played by sulfur. Relative abundances of sulfur to selenium in various types

of natural materials are shown in Table 3.2.1. Selenium tends to be relatively more abundant in materials in which the forms of the two constituents are selenide/sulfide, and least abundant in materials in which the forms are selenate/sulfate.

Under ambient conditions, elemental selenium occurs primarily as a gray solid consisting of long chains of covalently-bonded Se atoms. It may also occur as a red-colored, unstable Se_8 molecule, which is similar in structure to the stable form of elemental sulfur, and as red, glassy amorphous Se. Chain-forms crystallize in the hexagonal system; Se_8 forms crystallize in the monoclinic system (Crystal, 1973).

Selenium, like the other heavy Group VIb elements, has an electron configuration which allows the existence of three stable oxidation states, -2, +4, and +6. The three common ions corresponding to the oxidation states are, respectively, selenide ion ($Se^{=}$), selenite ion ($SeO_3^{=}$), and selenate ion ($SeO_4^{=}$). Selenium is capable of complexing with elements other than oxygen, particularly the halogens (e.g., $SeCl_4$, SeF_6), but such compounds are rare in nature.

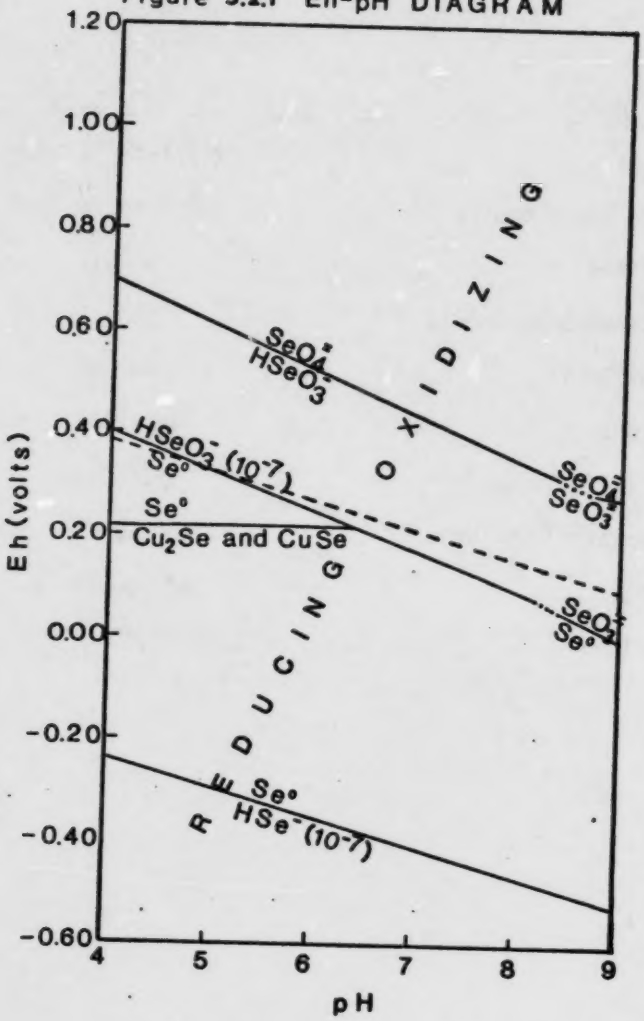
Stability of the elemental form and the three common ionic forms is controlled by Eh-pH ranges (Figure 3.2.1). Elemental selenium is stable under moderately reducing conditions; selenide ion is stable under moderately to strongly reducing conditions; selenite and selenate ions are stable under moderately to strongly oxidizing conditions, with the latter being the stable form at higher Eh's. For a given Eh, a higher oxidation state is favored with increasing pH. Since most natural surface waters lie within the range of positive Eh's and near-neutral pH's, the stable forms of selenium in most streams and reservoirs tend to be elemental selenium, selenite, and selenate.

TABLE 3.2.1

SULFUR/SELENIUM RATIOS OF COMMON EARTH MATERIALS (Compiled from Hashimoto and Winchester, 1967, Nazarenko and Ermakov, 1972 and Ruch, Gluskoter, and Shimp, 1974).

Material	S/Se
Oxidates	250:1 to 10,000:1
Sulfide Ore Deposits	400 1 to 250,000:1
Meteorites	3300:1
Argillaceous Sediments	3300:1
Igneous Rocks	6000:1
Limestones	15,000:1
Coal (Illinois Basin)	17,600:1
Sedimentary Iron Ores	100,000:1
Sea water	232,000:1
Evaporites	200,000,000:1

Figure 3.2.1 Eh-pH DIAGRAM



after Geering et al., 1968

However, selenide may occur in surface waters if the time from entry to analysis has not been sufficient to allow oxidation of original selenide to one of the higher oxidation states.

Selenium occurs in a large number of organic compounds, most commonly as a replacement for essential sulfur in compounds such as proteins. Further consideration of organo-selenium compounds is given in Chapter 4.

3.3 Selenium in Rocks

There are a total of more than fifty minerals in which selenium is an essential element. However, none of these are common. Rather, the principal occurrence of selenium within minerals is as a substitution for sulfur in sulfur-essential minerals which allows for the wide ranging occurrence of selenium in rocks of many types and environments of formation.

Selenium is most abundant in rocks which contain appreciable amounts of sulfide minerals, particularly copper sulfides. More than 90% of the production of selenium in the United States is the by-product of electrolytic refining of copper sulfide ores (Nazarenko and Ermakov, 1972). Additional selenium is recovered in the refining of sulfur, zinc, nickel, silver, and uranium.

Even at that, selenium abundances in most rocks are low. The average of all crustal rocks has been variously estimated to be from .03 to .8 ppm by weight, with a mean estimate of .05 ppm (Turekian and Wedepohl, 1961).

Among types of rocks which tend to have abnormally high Se contents, are volcanic rocks and shales. Because the former do not occur naturally in Illinois, they need no further consideration than to note that they may have very high Se contents (up to 1500 ppm), as has been so noted in parts of the western United States (Lakin, 1961b).

Connor and Shacklette (1975) reported analyses of two groups of shales from Missouri, Kansas, Oklahoma, and Arkansas which are similar in gross composition to the prevalent shales of Illinois. Geometric mean concentrations of selenium were .46 and .64 ppm. These high values are consonant with high sulfide contents of the same rocks. In the absence of better data, a reasonable assumption is that Illinois shales are likely to have selenium contents near these values, which are approximately an order of magnitude above those of most natural earth materials.

3.4 Rock Contributions to Se Content of Illinois Surface Waters

In the absence of better data, one might assume that Illinois rocks differ little in average selenium content from the examples noted above. Under this condition, an estimate of the average Se content of Illinois rocks would be on the order of .05 ppm by weight, or $5X10^{-8}$ of total rock weight. Average total dissolved solids concentration in Illinois streams is approximately 300 mg/l (Nienkerk and Flemal, 1976). Under the conditions that Se is liberated from rocks to streams at the same rate as other constituents are, and that all of the observed total dissolved solids derive from rocks, the expected average concentration of selenium in Illinois streams would be $1.5X10^{-5}$ mg/l (300 mg/l X $5X10^{-8}$). This value is well below the level of detection employed by the IEPA in selenium analyses (10^{-2} mg/l), and is part of the explanation for the low incidence of Se in Illinois surface waters (Chapter 6). This value is also conservative in the sense that neither of the implied conditions of equal rates of liberation and rock-source of TDS is true. Selenium is less soluble than most constituents of TDS, and much of the TDS load does not derive from rock solution; both of these considerations cause the estimate to err on the high side.

Even if it is assumed that the higher content of selenium associated with local shales (0.5 ppm) was pervasive in all Illinois rocks, the line of reasoning followed above would suggest an average Se content of surface waters of $1.5X10^{-4}$ mg/l. Like the above value, this figure is both conservative and well below detection levels.

It is possible that the highest selenium content in Illinois rocks occurs in the lead-zinc sulfide ore deposits of northwestern Illinois. However, there are no data to confirm this supposition. Even if it is true, there is no discernable impact on the area streams; all 105 of the IEPA analyses for selenium made on the Galena, Apple and Plum Rivers and on the headwaters of the Pecatonica River between 1972 and 1976 were below the level of detection.

3.5 Selenium in Coal

Coals typically have selenium concentrations in the range of 1.0 to 4.0 ppm (Table 3.5.1), which is considerably above the norm (0.05 ppm) for natural earth materials.

Illinois coals tend to have mean concentrations slightly lower than those of U.S. coals as a whole. Ruch, Gluskoter and Shimp (1974) analyzed a total of 82 coal samples from the Illinois Basin, 77 of which were collected from the geographic confines of Illinois. The basin samples averaged 1.99 ppm selenium, with a standard deviation of 0.93 and a range of 0.45 to 7.70. A histogram of the data is shown in Figure 3.5.1. No obvious difference in concentration was observed between individual coal seams.

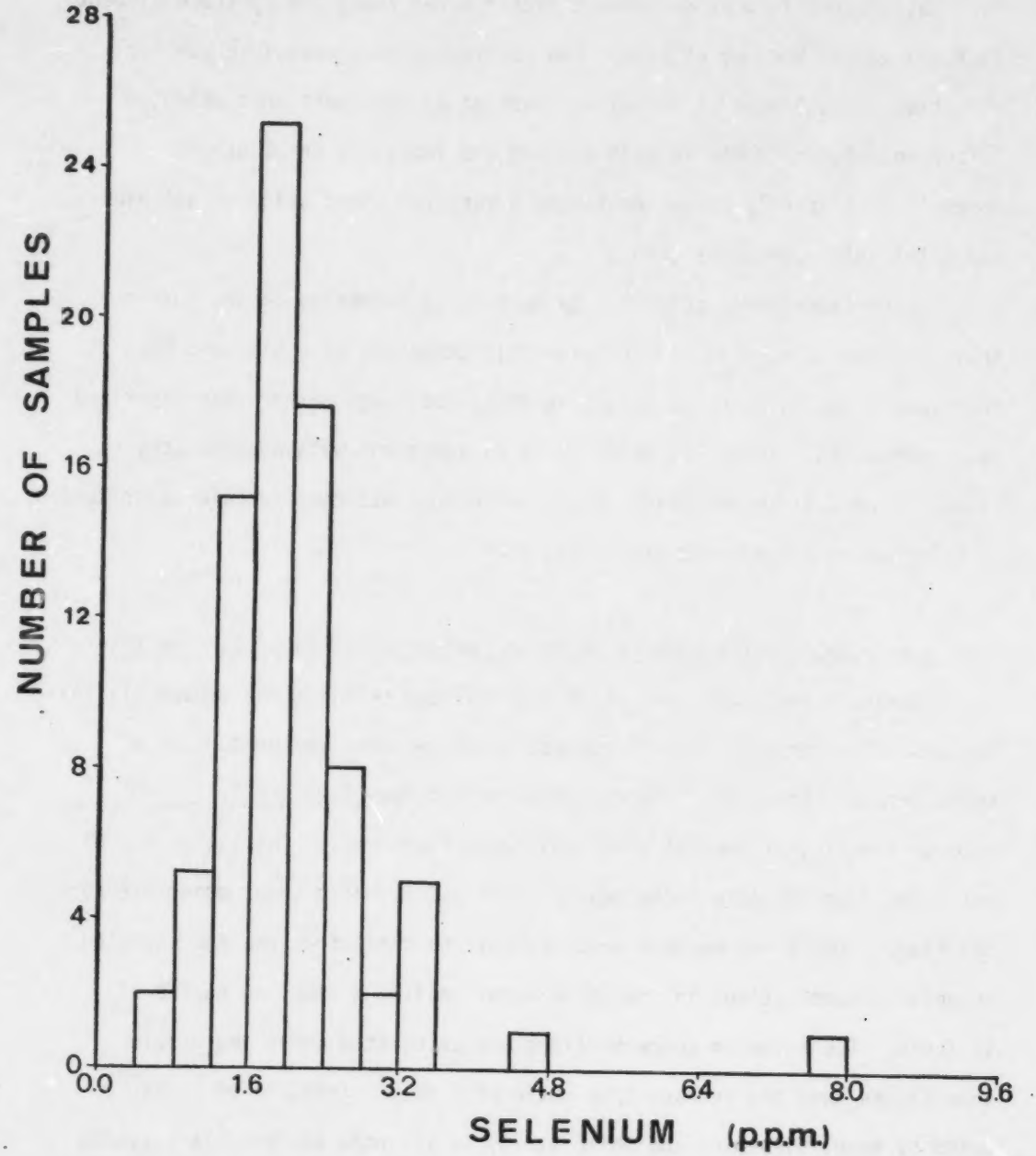
The enrichment factor for selenium in Illinois Basin coals, which is the ratio of mean coal concentration to crustal abundance, is approximately

TABLE 3.5.1

SELENIUM CONTENT OF U.S. COALS (Lakin, 1973)

State	Number of Samples	Selenium, ppm		
		Low	High	Average
Alabama	4	2.20	8.15	5.14
Colorado	3	1.25	2.05	1.65
Illinois	2	1.05	1.97	1.51
Indiana	4	1.41	8.36	3.96
Iowa	1	1.54	1.54	1.54
Kansas	1	2.27	2.27	2.27
Kentucky	5	1.71	4.82	3.13
Maryland	1	1.70	1.70	1.70
Missouri	2	3.41	4.98	4.19
Montana	3	2.20	4.11	3.04
New Mexico	2	4.43	4.82	4.62
North Dakota	1	0.98	0.98	0.98
Ohio	4	2.64	7.30	4.62
Pennsylvania	11	1.35	10.65	3.74
Tennessee	1	4.89	4.89	4.89
Utah	4	1.30	2.37	1.83
Virginia	4	2.24	6.13	4.37
Washington	2	0.46	0.66	0.56
West Virginia	20	0.92	6.80	3.36
Wyoming	1	3.43	3.43	3.43
Total 20	86	0.46	10.65	3.36

FIGURE 3.5.1 Selenium in Illinois Coals



after Ruch, et. al., 1974

40. This is the largest enrichment factor noted among the 23 trace elements included in the Ruch et al study, and points out that coal is a particularly effective concentrator of selenium. Ruch et al concluded that selenium is concentrated in coals in both organic and inorganic combinations. Somewhat surprisingly, their data show a very low correlation of selenium and total sulfur contents (r=0.2).

Ashing experiments conducted by Ruch et al suggested to the authors that selenium is a relatively non-volatile component of coals, and that it therefore ought to be concentrated in ashes and slags rather than vaporized upon combustion. This conclusion is in disagreement with observations (e.g., Andren, Klein and Talmi, 1975) which indicate considerable vaporization of selenium in actual combusion situations.

3.6 Coal Contribution to Selenium Content of Illinois Surface Waters

There are two routes via which coal-related selenium may impact Illinois streams. The first is through combustion of the coal and production of seleniferous wastes, which is discussed in sections 3.11 and 3.12, and through leaching of coal at mines and natural outcrops. The latter may be evaluated from the data presented in Table 3.6.1, which shows mean (Nienkerk and Flemal, 1976) and maximum observed sulfate concentrations and expected selenium concentrations in the three major coal-mine impacted basins of Illinois. The selenium concentrations are calculated under the triple assumptions that the average S/Se ratio of $1.8X10^4$ ($=SO_4/Se$ of $5.3X10^4$) noted by Ruch, Gluskoter and Shimp (1974) in Illinois Basin coals pervades all of the coals of the three stream basins, that all of the sulfate in the streams of the three basins derives from leaching of coals, and that there

TABLE 3.6.1

ESTIMATED SELENIUM CONTENT OF SELECTED ILLINOIS STREAM BASINS RESULTING FROM LEACHING OF COALS (see text).

Basin	Observed SO_4 (mg/l)		Estimated Se (mg/l)	
	Mean	Maximum	Mean	Maximum
Big Muddy River	92	3,500	.002	.07
Saline River	112	19,000	.002	.36
Mary's River	268	1,780	.005	.03

is no fractionation of selenium relative to sulfur during the leaching and stream transport.

Like the calculations of 3.4, the estimated selenium concentrations of Table 3.6.1 are conservative in that violation of any of the assumptions would decrease the estimates. Actual observed selenium concentrations in the three basins suggest that the assumptions are indeed violated: all of the 52 selenium analyses in the Mary's River drainage made by the IEPA from 1972 through 1976 were below the .01 mg/l level of detection; of the 304 selenium analyses in the Saline River drainage during the same period, 301 were below the level of detection and the remaining three were at the level of detection; and of the 396 analyses in the Big Muddy drainage, 393 were below the level of detection and the remaining three at the level of detection. On this basis, it may be concluded that leaching of coal deposits has the potential for producing moderate levels of selenium in certain Illinois streams, but that the actual impact is not large.

3.7 Selenium in Petroleum

Selenium content of petroleum tends to be approximately an order of magnitude lower than that of coal; two studies of U.S. crude oils produced extreme values of .06-3.4 ppm (Pillay, Thomas and Kaminski, 1969) and .026-1.4 ppm (Shah, Filby and Haller, 1970).

Mast and Ruch (1973) determined the selenium content of 46 samples of Illinois crude oils from ten stratigraphic intervals and various depth ranges (Table 3.7.1). Thirty-eight of the samples contained selenium below the level of detection which was employed (.04 ppm). The remaining eight had values ranging from .06 to .40 ppm. There was no discernable correlation between stratigraphic interval and selenium content, rock type and selenium

TABLE 3.7.1

SELENIUM CONTENT OF ILLINOIS CRUDE OILS (Mast and Ruch, 1973)

Stratigraphic Interval/ Pay Zone	Number of Samples	Depth Range (ft)	Lithology*	Selenium (ppm)** Min	Max
Pennsylvanian	3	479-950	S	n.d.	0.08
Kinkaid-Beech Ck	1	2125	S	n.d.	n.d.
Cypress	5	858-2308	S	n.d.	n.d.
Paint Creek	3	1511-1719	S	n.d.	n.d.
Aux Vasses	6	1718-3150	ST	n.d.	0.06
St. Genevieve	7	1860-3170	OL	n.d.	0.07
St. Louis-Borden	5	1352-3250	L/ST	n.d.	0.40
Devonian	5	438-3303	L/S/DS	n.d.	0.20
Silurian	7	1733-2184	L	n.d.	n.d.
Galena	4	2341-4492	L	n.d.	n.d.

* S, sandstone; ST, siltsonte; OL, oolitic limestone; L, limestone; DS, sandy dolomite.

** n.d., not detected (less than 0.04 ppm).

content, or depth and selenium content.

3.8 Selenium in Soils

Almost all soils contain at least trace amounts of selenium, with most soils containing between 0.1 and 2.0 ppm (Swaine, 1955). Soils of the eastern United States tend to have slightly higher concentrations than soils of the western United States (Table 3.8.1).

There are comparatively few analyses of selenium in Illinois soils. However, those that exist (Table 3.8.2) suggest that Illinois soils tend to have higher concentrations than the norm for U.S. soils. There is no obvious explanation for this condition. Neither is there any obvious pattern to the distribution or locale of the more seleniferous Illinois soils.

Interest in the selenium content of soils has been spurred by the discovery that some plants concentrate selenium from soils, and that ingestion of these plants can cause the livestock diseases "blind staggers" and "alkali disease". Neither of these diseases is known to be a problem in Illinois. This is consonant with the observation that total selenium content of soils bears little reltionship to concentration of selenium in vegetation (Lakin, 1973); soils of Hawaii that contain 6-15 ppm selenium and of Puerto Rico that contain up to 12 ppm selenium, do not produce seleniferous vegetation (Anderson et al, 1961; Lakin, 1973), whereas soils of South Dakota and Kansas that contain less than 1 ppm selenium do produce seleniferous (toxic) vegetation.

This condition stems partly from differences in types of vegetation. But the principal control appears to be the chemical form of the selenium in the soils. The prevalent form of selenium in well-drained, acid soils (Geering et al, 1968), such as those which typify Illinois, is basic ferric

TABLE 3.8.1

CONCENTRATION OF SELENIUM, IN PARTS PER MILLION, IN SAMPLES OF SOILS AND OTHER SURFICIAL MATERIALS FROM THE COTERMINOUS UNITED STATES (Shacklette, Boerngen, and Keith, 1974).

Area	Range	Geometric Mean	Arithmetic Mean
Entire Coterminous U.S. (N=912).....	0.1 - 4.32	0.31	0.45
Western U.S., west of 97th merdian (492)..	0.1 - 4.32	0.25	0.38
Eastern U.S., east of 97th meridan (420)..	0.1 - 3.88	0.39	0.52

TABLE 3.8.2

PERCENT OF SOIL SAMPLES WITHIN GIVEN RANGES OF SELENIUM CONCENTRATIONS (From Shacklette, Boerngen and Keith, 1974).

Range of Concentrations	U.S. Total (N=912)	Illinois Total (N=20)
0.0 - .130	16	5
.130 - .275	24	10
.275 - .460	26	15
.460 - .765	21	50
.765 - 4.000	13	20

selenite ($Fe_2(OH)SeO_3$), a compound which is relatively insoluble and, therefore, not readily available for uptake by plants. More soluble selenium compounds, typically selenates, are usually abundant only in alkaline soils of impeded drainage. Thus, it is the availability of selenium to plants, rather than the total amount of selenium, that is the critical variable in assessing the selenium toxicity of soils.

The impact of soil selenium on Illinois surface waters is apparently very low, as is indicated by the low incidence of selenium in Illinois surface waters (Chapter 6).

3.9 Selenium in Natural Waters

The selenium content of surface waters seems to have been systematically studied only in the waters of areas where it is known to be particularly plentiful. Thus, in South Dakota, in an area where selenium is locally abundant enough to be toxic, mean concentrations of .02 and .09 mg/l have been found in two ponds (Searight et al, 1946), and the Colorado and Missouri Rivers, which in places drain seleniferous soils, have been noted to contain as much as 2.68 mg/l of selenium (Williams and Byers, 1936) and 1.20 mg/l of selenium (Byers, 1935), respectively. The latter probably represent near extreme values for river and lake waters.

Kharkar, Turekian and Bertine (1968) estimated that the mean concentration of soluble selenium in the Mississippi River was $1.4X10^{-4}$, $1.1X10^{-4}$ mg/l of which was dissolved in the water and $0.3X10^{-4}$ mg/l of which was absorbed on particulate matter. This estimate remains as the best available data for the average selenium content of rivers and lakes.

Similarly, there is only scanty data on the selenium content of subsurface waters, and that, almost exclusively in areas known to have seleniferous soils and subsurface materials.

Study of seawater samples (Schutz and Turekian, 1965) indicates that

selenium is removed from seawater by some process or combination of processes. These conditions probably exist in fresh water environments as well, and implies that selenium is likely to be a non-conservative water component which is assimilated in aquatic environments. However, data is insufficient at this point to either assess the assimilation capacities of individual bodies of water or to determine the mechanism by which assimilation might occur

3.10 Selenium in Natural Waters of Illinois

The IEPA has systematically sampled Illinois surface waters for selenium since 1972. Of the 7822 analyses made through 1976, only 21 (.27%) contained selenium at or above the .01 mg/l level of detection (Table 3.10.1). If the 7801 samples which contained no detectable selenium are assumed to have had no selenium content, the resultant average concentration of the 7822 samples is $4.2X10^{-5}$ mg/l. Considering the inadequacy of the assumption, this value is sufficiently close to that of the selenium concentration of the waters of the Mississippi River Basin as a whole to suggest that Illinois surface waters are not atypical with respect to selenium.

Of the 21 samples at or above the level of detection, several appear to be related to point source discharges, and hence are not "natural". These are discussed in Chapter 6.

Although there is not much difference between the occurrences of selenium shown in individual basins (Table 3.10.2), it is of interest that all but five occurred on streams in the southern portion of the state, six of which occurred on a single stream, and six of which occurred in the two major strip-mine impacted drainages (Big Muddy and Saline Rivers).

TABLE 3.10.1

INCIDENCE OF DETECTABLE SELENIUM (≥ .01 mg/l) IN ILLINOIS SURFACE WATERS, 1972-1976 (Compiled from IEPA files).

ID NO.	River	Location	Ratio*	Date	Conc.
A 01	Ohio	Rondeau Island	1:15	11/30/76	0.01
AD 01	Cache	1 mi E. of Karnak	1:15	11/17/76	.01
AT 04	Saline	3 mi S. of Rt 13	1:17	8/18/76	.01
ATFJ01	Cane Creek	1.5 mi SW of Omaha	1:15	4/02/75	.01
ATG 03	Middle Fk, Saline	3 mi SE of Harrisburg	1:15	10/13/76	.01
BF 01	Sugar Creek-South	NE of Palestine	6:13	10/18/76	.02
				7/20/76	.04
				4/19/76	.02
				1/22/76	.01
				10/15/75	.03
				10/29/73	.01
C 06	Little Wabash	2 mi NW of Effingham	1:15	11/17/76	.01
EO 01	South Fk, Sangamon	1.5 mi NW of Rochester	1:15	8/07/75	.06
EOA 01	Sugar Creek	1 mi SE of Springfield	1:15	6/24/75	.01
G 01	DesPlaines	2 mi E of Chanahon	1:11	6/11/73	.01
GIX 01	Deep Run	Rt 7 Lockport	1:12	9/29/76	.01
HA 01	Grand Calumet	Torrence Ave at Burhnam	1:11	5/09/75	.01
I 81	Mississippi	Cape Rock, Cape Girardeau	1:4	8/14/73	.01
N 01	Big Muddy	5 mi S of Grand Tower	1:15	12/03/76	.01
ND 03	Crab Orchard Creek	1.5 mi S of Marion	1:14	8/04/76	.01
NF 01	Hurricane Creek	4 mi WNW of Herrin	1:16	1/07/77	.01

*Ratio, number of samples in which selenium was found in measurable concentrations to number of samples analyzed

TABLE 3.10.2

RECORD OF IEPA SELENIUM ANALYSES OF SURFACE WATERS, BY BASIN, 1972-1976.

Code	Basin	Ratio*
A	Ohio, exclusive of Saline	2:209
AT	Saline	3:304
B&C	Wabash	7:711
D	Illinois	0:837
DT	Fox	0:489
E	Sangamon	2:442
F	Kankakee	0:89
G&H	Des Plaines	3:1420
I	Mississippi, South	1:128
J	Mississippi, South Central	0:234
K	Mississippi, Central	0:109
L	Mississippi, North Central	0:116
M	Mississippi, North	0:124
N	Big Muddy	3:396
O	Kaskaskia	0:329
P	Rock	0:430
Q	Lake Michigan	0:1455
	Total	21:7822

*Ratio, number of samples in which selenium was found in measurable concentrations to number of samples analyzed.

Water used for public and private water supplies, both surface and ground waters, has an even lower incidence of selenium. The more than 6000 analyses for selenium, made in the approximately 4-year period during which the IEPA has been making such analyses, have produced only a single detectable selenium reading. This reading was at the minimum level of detection (.01 mg/l) and subsequent re-analysis of the same source failed to confirm even this amount.

3.11 Selenium in the Atmosphere

It has been only recently that atmospheric concentrations of selenium have been investigated. In the pioneering work, Hashimoto and Winchester (1967) showed that atmospheric selenium is associated with sulfur in much the same manner and ratio as in common earth materials.

Hashimoto, Hwang and Yanagisawa (1970) investigated possible sources of atmospheric selenium on the assumption that they are the same as sources of atmospheric sulfur. Analyses of heavy and raw petroleum were found to have ratios of Se/S sufficiently close to the Se/S ratios in precipitation to suggest that petroleum combustion is a likely source of the atmospheric selenium.

Johnson (1970) suggested that a major source of atmospheric selenium is the combustion of solid wastes. He pointed out that over 70% of all combustible solid waste is paper, and that West (1968) had previously reported the presence of selenium in all types of papers. Analyses of the selenium content in common types of paper product and in municipal solid wastes, composts and incinerator by-products (Table 3.11.1) suggested to Johnson that the levels of selenium present in these materials is an indication of the amount of selenium introduced into the atmosphere by their incineration.

TABLE 3.11.1

DETERMINATION OF SELENIUM IN SOLID WASTE AND SOLID WASTE-RELATED MATERIALS (Johnson, 1970).

Material	No. of samples	µg./g. d.wt. Av.	µg./g. d.wt. Range	mg./liter	Stack emission µg./M^3	Stack emission lb./Se/ton refuse
Newspaper	8	8.6	2.3-18.3			
Cardboard	8	2.8	1.6-5.1			
Laboratory tissue	4	7.1	1.6-19.5			
Municipal solid waste 1[a]	2	4.41	4.08-4.74			8.82×10^{-3}
Municipal solid waste 2[a]	4	1.08	0.92-1.30			2.16×10^{-3}
Municipal solid waste 3[b]	3	0.49	0.29-0.59			9.80×10^{-4}
Synthetic refuse	3	4.5	3.07-5.9			
Incinerator I[c] fly ash quench water	1			0.023		
Incinerator I residue quench water	1			0.003		
Incinerator I residue	1	0.003				
Incinerator I tap water	1			[d]		
Incinerator II[e] stack emission[f]	1	0.7[g]			0.23	3.65×10^{-6}
Incinerator stack emission[h]	1	14.5[g]			0.24	3.76×10^{-6}
Finished compost A	3	0.76	0.54-0.91			
Finished compost B	3	0.43	0.38-0.52			

[a]Ground in hammermill and blended in double-cone homogenizer.
[b]Ground in Wiley mill.
[c]Reciprocating grate, continuous feed 300-ton-per-day capacity, two furnaces operating
[d]None detected.
[e]Conical burner, continuous feeding with screw conveyor, 0.595 ton per hour burned.
[f]Inlet of electrostatic precipitator.
[g]Micrograms of selenium per gram of particulate collected.
[h]Outlet of electrostatic precipitator.

Andren, Klein & Talmi (1975) investigated the production of atmospheric selenium by a coal-burning power plant fitted with "the latest available particulate pollution abatement equipment" They found that approximately 32% of the selenium in the coal was emitted in vapor form, and an additional small fraction escaped as fly ash. Due to the comparatively high volatility of selenium at combustion temperatures, only 0.3% of the selenium was retained in slag. The remaining portion was trapped by the pollution abstract equipment. On the basis of this study, the authors concluded that 1.5 to 2.5 times as much selenium is mobilized into the atmosphere as the result of fossil fuel combustion as is added by natural processes.

Selenium and sulfur contents of the Greenland ice sheet have been investigated to determine if atmospheric selenium is capable of the same long distance transport displayed by atmospheric sulfur (Weiss, Koide and Goldberg, 1971). It was found that the amount of selenium remained constant throughout the time interval recorded in the glacial ice. Sulfur, on the other hand, increased greatly beginning in 1882. On this basis, it was concluded that the selenium introduced into the atmosphere as the result of fossil-fuel combustion behaves in a manner fundamentally different from that of similarly derived sulfur. In particular, the oxidized form of selenium produced by high temperature combustion (SeO_2) is readily reduced such that even "specks of oxidizable dust in the air react with it to form red elemental selenium" (Weiss et al, 1971), which is easily washed out of the atmosphere. Only that portion of atmospheric selenium which is biologically derived was considered to have sufficiently long residence times to allow its wide dispersal.

3.12 Atmospheric Contributions to Se Content of Illinois Surface Waters

Flemal (1977) estimated the average sulfate concentrations in all

Illinois streams and in the DesPlaines River basin due to atmospheric deposition, according to the source of the atmospheric sulfate (Table 2.12.1, columns 1 and 4). If the Se/S ratio of 10^{-4} (=Se/SO_4 ratio of $3X10^{-5}$), noted by Hashimoto and Winchester (1967) in precipitation samples on the eastern seaboard, can be assumed to hold for Illinois as well, equivalent Se concentrations can be estimated (Table 3.12.1, columns 2 and 4). The concentrations as estimated also assume that there is no fractionation of Se relative to S from time of deposition from the atmosphere to time of stream analysis. The tendency for Se to form insoluble compounds argues that this is probably not a reasonable assumption, and therefore the table values tend to overestimate the Se concentrations.

Although there is considerable latitude for error in these data, they do suggest that the atmosphere is probably the source of a large portion of the small amount of selenium which has been observed in Illinois stream waters. Comparison of these data with the data of 3.4 imply that the relative contribution of atmospherically-derived selenium is likely to be greater than that of rock-derived selenium in most Illinois streams.

3.13 Industrial Uses of Selenium

In spite of its relatively low abundance in earth materials, selenium is both readily available and widely used in industrial applications. Availability stems from the source of selenium as a by-product of sulfide ore refinement. The many uses stem from the wide range of advantageous chemical and physical properties exhibited by selenium and its compounds. In 1974, the last year of available statistics, total U.S. comsumption of selenium consisted of over 1.5 million pounds, a 14% increase over the previous year (United States Department of the Interior, 1976).

TABLE 3.12.1

ESTIMATED ATMOSPHERIC CONTRIBUTION OF SULFATE AND SELENIUM TO ILLINOIS STREAM WATERS, ACCORDING TO SOURCE. IN MILLIGRAM PER LITER AT AVERAGE DISCHARGE (see text).

	All Illinois Streams		DesPlaines River Basin	
Source to Atmosphere	SO_4	Se	SO_4	Se
Anthropogenic	63.8	.002	146.3	.004
Natural Processes	6.0	.0002	4.1	.0001
Recycled Sea Salt	2.0	.00006	.1	.000003
Total Atmospheric	70.0	.002	150.5	.004

The major consumers of selenium are the electronics and photo-reproduction industries, which in 1974 accounted for 45% of total U.S. consumption (USDI, 1976). Because selenium offers differential resistence to electrical currents, it is useful in constructing rectifiers. It also changes resistence in response to changes in intensity of incident light, which allows it to be used in photovoltaic cells and light meters. Selenium is also used as a "doping" agent to alter the electron balance in semiconductor crystals such as transistors and diodes. In xerography, selenium photoreceptors act to hold a latent image of the material to be copied until the image can be electrostatically transferred to paper.

In glass and ceramics industries, selenium is used as an oxidizing agent to decolor high-iron glass and, in combination with other compounds, as a pigment enhancer. These applications accounted for 34% of U.S. consumption in 1974 (USDI, 1976).

In its major use in the industrial chemical field, cadmium sulfoselenate compounds are used widely as heat-resistant red pigments in plastics, paints, inks, and enamels. Small amounts of ferroselenium are added to stainless steel to improve its casting, forging, and machining characteristics.

Pharmaceutical preparations accounted for the consumption of 50,000 pounds of selenium in 1974 (USDI, 1976). As sodium selenite it is also widely used as a nutritional additive in poultry and swine feeds.

Among many other uses are 1) general purpose oxidizing agent, 2) preservative in inks, oils, and lubricants, 3) dehydrogenator of alicyclic compounds, 4) cracking catalyst in petroleum refinement, 5) catalyst in the hardening of liquid oils, 6) hardener of rubber products, 7) insecticide

and fungicide agent, 8) anti-knock component of gasoline, 9) flameproofing of electrical wiring, and 10) detection of mercury vapors.

Considering the wide range of industrial uses of selenium, and the range of consumer products which contain the element, it may be expected that industrial selenium has a near ubiquitous presence in the environment.

3.14 Selenium in Effluent, General

There is no known systematic study of the selenium content of effluent discharges. In the absence of better data, the performance of Illinois dischargers (section 3.15) serves as the best guide for the expected selenium content of effluents.

3.15 Selenium in Effluent, Illinois

The IEPA has included selenium among constituents analyzed in effluent discharges since 1972. Through December 1976, a total of 2172 such analyses had been generated. The majority of these, 2136 (98.3%) have shown no detectable selenium; the remaining 36 (1.7%) have shown various levels ranging up to the maximum observed, 3.08 mg/l.

Table 3.15.1 shows the sampling record by type of discharge. The majority of samples, 1336 (61.5%), were drawn from various types of sewage treatment works, which collectively produced six of the 36 detectable selenium readings. Notable is that one sewage treatment works (Rockford) was responsible for half of these six (Table 3.15.2), as well as for the only reading from sewage treatment works which exceeded the minimum level of detection (.01 mg/l). Also included in the Rockford record are 20 samples in which there was no detectable selenium.

The record for industrial discharges is strongly dependent upon type of industry. The most notable record is for the petroleum refining industry,

TABLE 3.15.1

INCIDENCE OF DETECTABLE SELENIUM (≥.01 mg/l) IN EFFLUENT DISCHARGES, 1972-1976, BY TYPE OF EFFLUENT, STATE OF ILLINOIS (Compiled from IEPA files).

	Ratio*	
Sewage Treatment Works		6:1336
1) Municipal	6:1158	
2) Miscellaneous Residential	0:66	
3) Recreational and Service Areas	0:47	
4) Motels and Mobil Home Parks	0:36	
5) Schools	0:29	
Industrial Discharges		29:636
1) Metals (Smelting and Plating)	1:146	
2) Chemical	4:87	
3) Heavy Industry	0:66	
4) Cooling Water (all industries)	0:54	
5) Utilities/Electricity Generation	0:44	
6) Petroleum Refining	22:34	
7) Electronics	0:34	
8) Agriculture and Food Products	0:31	
9) Rubber	0:27	
10) Glass Manufacturing	0:18	
11) Printing	0:12	
12) Stone Products	3:5	
13) Miscellaneous Manufacturing	0:82	

Unknown Sources		0:200
	Total	36:2172

*Ratio, number of samples in which selenium was found in measurable concentrations to number of samples analyzed.

TABLE 3.15.2

SELENIUM CONTENT OF ILLINOIS EFFLUENT DISCHARGES IN MG/L: SEWAGE TREATMENT WORKS WITH ONE OR MORE ANALYSES ABOVE THE LEVEL OF DETECTION (0.01 mg/l).

Name	IEPA ID No.	Location	Ratio*	Detectable Readings Date	Conc.
Elizabethtown STW	A 01 069	Elizabethtown	1:2	10/23/72	.01
Manteno STW	FFB 01 091	Manteno	1:1	2/22/73	.01
Rockford SD	P 02 201	Rockford	3:23	6/05/75	.01
				5/20/75	.01
				3/06/73	.12
Freeport STW	PW 01 177	Freeport	1:14	6/06/73	.01

*Ratio, number of samples in which selenium was found in measurable concentrations to number of samples analyzed.

which produced detectable selenium in 22 of 34 samples (64.7%), and particularly for refineries which also recover elemental sulfur (Table 3.15.3). The latter subcategory showed detectable selenium in 18 of 22 samples (81.8%), and accounted for the two largest recorded readings. Malhotra and Smith (1976) reported the existence of four plants in Illinois which recover elemental sulfur. Three of these occur in Table 3.15.3. The remaining plant, is Anlin Company of Madison, which recovers elemental sulfur from the gas streams of nearby Shell, Clark and Amoco refineries (U.S. Department of Interior, 1974), which are three of the remaining four selenium shows among refineries (Table 3.15.3) has no record of analyses of its discharges in IEPA files.

Other industries which have had incidence of detectable selenium in their discharges are the stone products and chemical industries. However, the distribution of these occurrences is limited to a few plants: all three of the detectable readings from stone products industries have come from two operations, both owned by Marblehead Lime Company (Table 3.15.4), and all four from the chemical industry have come from two operations, Chemetco Corporation of Alton, and Pierce Chemical Company of Rockford. The latter two dischargers have each been sampled twice, and have had selenium shows in each of the four analyses.

The record of Illinois effluent sampling for selenium is both limited and selective. Three thousand three (77.6%) of the point source dischargers carried on IEPA records have never been sampled for selenium, 388 (10.0%) have been sampled only once, and only 83 (2.1%) have been sampled as many as five times. Among those not sampled, or sampled only once, are many which are possible producers of seleniferous wastes. Notable among these are strip

TABLE 3.15.3

SELENIUM CONTENT OF ILLINOIS EFFLUENT DISCHARGERS, IN MG/L: PETROLEUM REFINERIES AND RECOVERERS OF ELEMENTAL SULFUR** WITH ONE OR MORE ANALYSES ABOVE THE LEVEL OF DETECTION (.01 mg/l).

Name	IEPA ID No.	Location	Ratio*	Detectable Readings Date	Conc.
Marathon Oil Co.**	BF 01 033	Robinson	11:13	9/27/76	0.6
				8/17/76	.04
				7/20/76	.04
				6/21/76	.03
				5/18/76	.03
				4/19/76	.05
				10/15/75	.06
				9/08/75	.03
				7/15/75	.04
				6/24/75	3.08
				4/18/73	.02
Mobil Oil - Joliet**	G 26 194	Joliet	6:8	12/04/75	.03
				11/13/75	.03
				11/14/74	.2
				4/11/74	.04
				8/21/73	.18
				12/21/72	.01
Union Oil Co.**	GI 02 197	Lemont	1:1	8/13/74	.02
Texaco Oil Co.	GIX 01 197	Lockport	1:2	12/04/75	.01
Shell Oil Co.	J 06 119	Wood River	1:2	10/26/72	.01
Clark Oil Co.	J 11 119	Hartford	1:3	11/05/76	.01
Amoco Oil Co.	J 12 119	Wood River	1:2	11/94/75	.04

*Ratio, number of samples in which selenium was found in concentrations to number of samples analyzed.

TABLE 3.15.4

SELENIUM CONTENT OF EFFLUENT DISCHARGERS, IN MG/L: MISCELLANEOUS DISCHARGERS WITH ONE OR MORE ANALYSES ABOVE THE LEVEL OF DETECTION (.01 mg/l).

Name	IEPA ID No.	Location	Ratio*	Detectable Readings	
				Date	Conc.
Marblehead Lime Co.	D 18 099	Marseilles	2:3	7/02/73	0.01
				4/18/73	.02
Amax Aluminum	DW 03 063	Morris	1:4	6/25/73	.01
Marblehead Lime Co.	HBD 06 031	Thornton	1:1	11/19/75	.01
Chemetco Corp.	JQ 07 119	Alton	2:2	12/12/73	.02
				10/31/72	.15
Pierce Chemical Co.	PSB 02 201	Rockford	2:2	7/14/76	.03
				7/31/74	.22

*Ratio, number of samples in which selenium was found in measurable concentrations to number of samples analyzed.

mine effluents, for which there is not a single selenium analysis. Industries known to use selenium or suspected of producing seleniferous wastes are similarly under-represented, considering their possible significance. Among these are the electronics industry (34 analyses), glass industry (18 analyses), paper products industry (2 analyses), and paint industry (no analyses).

The two industries which Patterson (1976) cited as appearing to be the best characterized industrial sources of selenium wastewater, electrolytic copper refining and zinc smelting, have no representation in the Illinois record. There are no copper refineries in the state (Malhotra and Smith, 1976) and the single primary zinc smelter, American Metal Climax of Sauget, discharges to the Sauget Sewage Treatment Works (Huff and Huff, 1976). The Sauget STW has had two selenium analyses made on its effluent, neither of which produced detectable selenium. The two secondary smelters of zinc, Apex Smelting Company of Chicago and Sandoval Zinc Company of Sandoval (Malhotra and Smith, 1976), similarly do not have independent discharges.

Chapter 4

OCCURRENCES OF SELENIUM, ORGANIC

4.1 Introduction

Selenium is a biologically essential nutrient element, necessary for normal healthy growth and fertility in plants, animals and probably also in man. However, in excess quantities it is also a toxicant capable of producing a variety of diseases and malformations. Problems associated with this ambivalent behavior are compounded by a limited knowledge of the threshold concentrations which separate the two disparate properties, and of the specific role(s) played by selenium in metabolism.

4.2 Selenium in Vegetation

Selenium is apparently an essential element in certain varieties of vegetation. Other plants are apparently incapable of distinguishing selenium from essential sulfur. Hence, almost all plant tissue contains at least trace quantities of the element (Tables 4.2.1 and 4.2.2). However, there is considerable variation in selenium levels between plant species and between the same species in different locales. Within-species variation appears to be a function of the absolute amount of selenium in the local soils, as well as the chemical form of the soil selenium.

Byers, Williams and Lakin (1938) grouped plants into three categories based on their selenium assimilation capacities. Those of the first group, which includes mostly grasses, absorb relatively little selenium. The second group, which includes cereals and many varieties of native plants, absorbs moderate amounts of selenium. The third group includes species which readily biosynthesize organic selenium compounds from inorganic selenium (Shrift, 1964). The latter are termed accumulator, or indicator, species. They have an added significance

TABLE 4.2.1

SELENIUM IN CULTIVATED PLANTS (DRIED), PPM, MISSOURI (Connor and Shacklette, 1975)

	Corn			Soybean		
Environment	Ratio*	Geometric Mean	Geometric Deviation	Ratio*	Geometric Mean	Geometric Deviation
Floodplain Forest	8:8	0.062	2.41	10:10	0.17	2.68
Glaciated Prairie	10:10	.072	2.61	10:10	.098	1.83
Unglaciated Prairie	10:10	.047	1.88	8:8	.097	2.28
Oak-Hickory Forest	10:10	.040	2.96	9:9	.077	1.94

*Ratio, number of samples in which the element was found in measureable concentrations to number of samples analyzed.

TABLE 4.2.2

SELENIUM IN NATIVE PLANT SPECIES (DRIED) PPM. FROM MISSOURI UNLESS NOTED (Connor and Shacklette, 1975).

Species	Ratio*	Geometric Mean
Buckbush	227:227	0.033
Cedar	50:50	.021
Hickory, Shagbark	26:26	.023
Oak, Post	46:49	.020
Oak, White	96:99	.018
Oak, Willow	45:45	.032
Pine, Shortleaf	49:49	.062
Sumac, Smooth	135:147	.020
Sweetgum	47:47	.065
Sagebrush (Wyo & Mont)	48:48	.420

*Ratio, number of samples in which the element was found in measurable concentrations to number of samples analyzed.

in that, by fixing large amounts of organo-selenium compounds, they make selenium available in a form readily usable by most other types of vegetation. Genera and common names of major accumulator plants are given in table 4.2.3. None of these are common in Illinois.

Selenium in tissues of most plants occurs as a replacement for sulfur in the amino acids methionine and cysteine, forming selenomethionine and selenocysteine, respectively. Most plants are incapable of distinguishing the selenium varieties from the sulfur varieties, and incorporate both into proteins. Accumulator plants are an apparent exception in that the selenium in them tends to be incorporated into the non-protein amino acids, Se-methylcysteine and Se-methlyselenocysteine. Synthesis of these compounds may serve as a detoxifying mechanism whereby selenocysteine is prevented from being excessively incorporated into proteins (Virupaksha and Shrift, 1965).

High levels of selenium in plants can cause disease in animals which ingest the plants. Grazing animals are particularly susceptible to such diseases; all species of plants are apparently capable of taking up selenium in quantities harmful to grazing animals if sufficient available selenium occurs in the soil (Lakin, 1972). Among crop plants which are known to be capable of accumulating disease-inducing concentrations of selenium are wheat, lettuce, cabbage and most members of the legume family. Crop plants that are known to metabolize large amounts of sulfur, such as mustard and onion, may also accumulate selenium in toxic amounts.

No systematic survey of the selenium content of Illinois vegetation is known. However, Figure 4.2.1 suggests that Illinois vegetation tends to contain selenium below that of the norm for U.S. vegetation, and perhaps below the optimum nutrient level for vegetation. This is in spite of the apparent above normal con-

TABLE 4.2.3

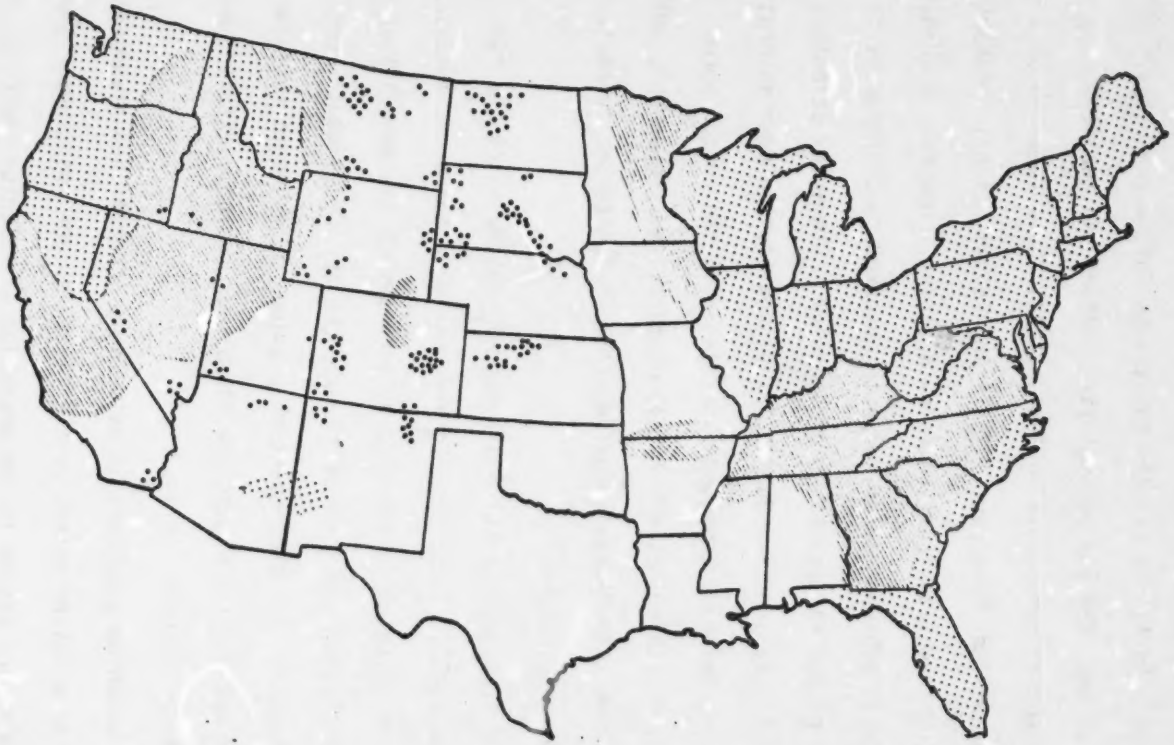
MAJOR ACCUMULATOR PLANTS (Shrift, 1973).

Genus	Family	Common Name
Astragalus	Leguminosae	Milk Vetch
Xyllorhiza	Compositae	Woody Aster
Haplopapus	Compositae	Goldenweed
Stanleya	Cruciferae	Prince's Plume

Secondary Accumulator Plants (Shrift, 1973)

Genus	Family	Common Name
Aster	Compositae	Wild Aster
Atriplex	Chenopodiaceae	Saltbush
Castillija	Scrophulariaceae	Paint brush
Comandra	Santalaceae	Bastard toad-flax
Grayia	Chenopodiaceae	
Grindelia	Compositae	Gumplant
Gutierrezia	Compositae	Snakeweed, matchweed
Machaeranthera	Compositae	
Sideranthus	Compositae	

FIGURE 4.21. SELENIUM IN PLANTS IN THE UNITED STATES



Low - approximately 80% of all grains and forages contain <0.05 p.p.m. of selenium.

Variable - approximately 50% of all grains and forages contain >0.1 p.p.m. of selenium.

Adequate - 80% of all grains and forages contain >0.1 p.p.m. of selenium.

• Local areas where selenium accumulator plants contain >50 p.p.m.

Reproduced from Micronutrients in Agriculture, 1972

centration of selenium in Illinois soils (section 3.8).

4.3 Metabolism of Selenium by Animals

The metabolism of selenium by animals appears to follow two paths. In large dosages, most of the selenium behaves like sulfur, and replaces that element in sulfur-essential compounds; in low dosages, there seems to be a separate selenium metabolism (Levander, 1976). This distinction is probably critical in the duel nutrient/toxicant roles of selenium. However, a quantitative picture of the metabolic behavior of selenium is obscured by differences in the behavior and potency of the various forms of selenium. Elemental selenium, for example, is practically inactive due to low solubility and poor absorption. In contrast, the organo-selenium compounds, particularly the common forms, selenocysteine and selenomethionine, are readily metabolized (Underwood, 1971). The activity of the common inorganic selenium salts, selenite and selenate, tends to fall somewhere in between.

Soluble forms of selenium compounds are readily dispersed by the circulatory system (Lee, 1969). These tend to accumulate in the detoxifying organs, although the amount of selenium in all tissues varies with the quantity and form of the administered selenium, the type of tissue, the tissues susceptibility to selenium intoxification, and the amount of previous exposure to selenium (Martin, 1973). The detoxifying organs are those most commonly affected by selenium-excess diseases (Martin, 1973).

Elimination of selenium compounds in animals is accomplished predominantly by the kidneys, and to a lesser extent by the liver, spleen and lungs. The importance of the pulmonary system in the excretion of selenium increases with increasing dosages of selenium (Martin, 1973). Retention of selenium in tissues depends on the amount administered; the higher the dosage, the lower the percent

retained (Hopkins, 1966). Organic selenium compounds are retained longer that are inorganic compounds, and selenium in protein amino acids is retained longer than in non-protein amino acids.

Most of the work on metabolic behavior of selenium has been done on laboratory animals. Burke (1976) summarized the comparatively few studies done on humans. On the basis of these, it appears that man is less efficient in absorbing selenium than are laboratory animals; three healthy humans absorbed between 44 and 70% of ingested selenium, versus a 90% rate for laboratory rats. Human excretion of selenium also varies according to the form of the selenium, with selenomethionine being excreted less rapidly than selenite; the biologic half-life of the two compounds is 70 and 65 days, respectively. Normal dietary intake in the U.S. is about 25 to 200 micrograms of selenium per day.

Although there appears to be no consistency in selenium concentrations observed in human organs (Burke, 1976), those in most blood samples tend to be fairly well regulated at about 0.2 ppm. Allaway et al (1968) found that whole blood samples from 19 different bloodbank locations throughout the U.S. showed a range of concentrations from 0.1 to 0.34 ppm, and that the concentration differences reflected differences in the selenium content of soils and crops in the geographic regions where the samples were taken. The lowest sample mean was .157 ppm, from 10 samples from Lima, Ohio, a known selenium-deficient area. Twenty samples from Rapid City, South Dakota, a selenium-adequate area, produced the high mean of .257 ppm. It is interesting to note that the mean level of selenium in human blood is twenty times that of the permissible level in Illinois public water supplies (section 5.3).

Several recent studies (e.g. Levander and Argrett, 1969) have indicated a possible interrelationship between the metabolic roles of selenium, cadmium, mercury, silver and lead. In particular, it may be that selenium works to reduce or neutralize the toxicities of the other elements (Mason and Young, 1967).

4.4 Nutritional Aspects of Selenium

In 1957, Schwarz and Foltz showed that selenium supplements could prevent liver necrosis in rats and exudative diathesis in chickens. Subsequent studies have shown that a large number of animal diseases can be so prevented (Table 4.4.1).

Studies have also shown that there is a strong relationship between vitamin E and selenium in many nutrient deficiency disorders (Table 4.4.1), but how the two interact remains uncertain. Some diseases previously thought to be solely due to vitamin E deficiencies have since been shown to be curable with selenium supplements alone. Others require supplements of both the vitamin and selenium (Scott, 1973).

An additional class of selenium deficiency diseases appears to be unrelated to vitamin E. Chickens fed selenium-free diets, adequate in all other known nutrients including vitamin E, exhibit poor growth, poor feathering, and degeneration of the pancreas (Thompson and Scott, 1970). Evidence such as this caused the Federal Food and Drug Administration, in February, 1974 to adopt a minimum dietary requirement for available selenium at 0.1 ppm in chicken and swine feed, and at 0.2 ppm in turkey feed (U.S. Dept. of Interior, 1976). Since these levels are well above the median values encountered in most natural feeds in Illinois, selenium must be provided in dietary supplements in the state.

Low levels of selenium in the blood of organically-fed chickens, like that of humans (section 4.3), correlates strongly with levels of selenium in local soils and vegetation. Geographic areas in which vegetation is naturally deficient in selenium, such as the general northeastern area of the U.S. and including Illinois (Figure 4.2.1), have been broadly recognized. In general, areas characterized as being selenium deficient are more widespread than areas characterized as possessing adequate selenium (Underwood, 1971).

TABLE 4.4.1

SELENIUM/VITAMIN E DEFICIENCY DISEASES (Scott, 1973).

Disease or Condition	Experimental Animal	Prevented by: Vitamin E	Selenium
I. Reproductive Failure			
Embryonic Degeneration			
Type A	Female rat, hen, turkey	X	
Type B	Cow, ewe		X
Sterility	Male rat, guinea pig, hamster	X	
II. Ailments of Liver, Blood, Brain, Capillaries, Pancreas			
Liver Necrosis	Rat, pig, beef calves	X	X
Fibrosis	Chick, mouse		X
Erthocyte Hemolysis	Rat, chick, man, premature human infant	X	
Plasma Protein loss	Chick, turkey	X	X
Anemia	Monkey	X	
Encephalomalacia	Chick	X	
Exudative Diathesis	Chick, turkey	X	X
Kidney Degeneration	Rat, mouse, monkey, mink	X	X
Steatitis	Mink, pig, chick	X	
Depigmentation	Rat	X	
Hair and Feather Loss	Chick, rat, horse, pig		X
III. Nutritional Myopathies			
Type A (nutritional muscular dystrophy)	Rabbit, guinea pig, monkey, duck, mouse, mink	X	
Type B (white muscle disease)	Lamb, calf, kid		X
Type C	Turkey		X
Type D	Chicken	X	

In spite of the FDA's action on dietary requirements for chickens, turkeys and swine, it remains difficult to assign the precise levels of selenium in herbage and livestock feed necessary to prevent deficiency diseases. In part, this condition stems from complications introduced by the presence of other compounds in feed stuffs. For example, sulfur in the soil may replace some selenium incorporated into plants, and thereby reduce the amount available to animal consumers. Selenium may also be diverted to sulfur metabolism pathways, and thereby be excluded from its independent roles. In general, selenium requirements are probably higher when sulfur intake in also high (Underwood, 1971). However, the amount of required dietary selenium is lower in the presence of an adequate vitamin E intake (Thompson & Scott, 1970).

Evidence has never clearly defined selenium deficiency in human populations, even in areas where it has been shown to occur in animals. Some studies, however, have produced evidence that selenium is a complicating factor in the protein deficiency disease, kwashiorkor. Investigations by Burk et al (1967) on Guatemalan children showed mean blood selenium levels of .08 ppm in untreated cases of kwashiorkor, .14 ppm in recovering cases, and .23 ppm in healthy children. One explanation of the low blood selenium levels in kwashiorkor cases is that patients are anemic and acutely depleted of protein and, therefore, circulate only small amounts of selenium-containing protein. However, selenium supplements in doses of 25-50 grams per day have produced prompt weight gains and reticulocytosis in children stricken with kwashiorkor after they did not respond to protein feedings, suggesting that selenium itself was necessary for complete recovery.

There has also been some evidence which implies that selenium may play a role in the prevention of some human cancers (e.g., Shamberger, Tytko and Willis, 1973), and that selenium deficiency may be an underlying

cause of various chronic human diseases, including cardiovascular disease (Frost, 1977).

4.5 Toxic Aspects of Selenium

Naturally occuring selenium poisoning has long been recognized as a problem for livestock grazing on seleniferous ranges (Martin, 1973). Resulting disorders range from a mild, chronic condition to acute poisoning, ending in death (Rosenfeld and Beath, 1964). Acute toxicity conditions can result from the consumption of selenium accumulator plants, which build up extremely high concentrations of selenium in their tissues (section 4.2). Milder, chronic disorders result from ingestion of normal herbage and grains grown on seleniferous soils. Symptoms vary from listlessness, inappetance, loss of hair, and soreness of hoofs in chronic "alkali disease", to blindness, abdominal pain and paralysis in the acute form called "blind staggers" (Underwood, 1971). The minimum toxic level in herbage for grazing animals is probably around 5 ppm (Underwood, 1971).

Among other terrestrial animals, seleniferous feed and injections have been observed to cause embryonic malformations in chicks (Franke, et. al. 1936), and anemia and severe pathological changes in the livers of dogs and rats (e.g. Moxon & Rhian, 1943). Seleniferous grain diets containing 5 ppm selenium reduce hatchability of chicks slightly, and diets containing 5-10 ppm and 10-15 ppm have been shown to induce disease symptoms in rats and dogs, and young pigs, respectively (Poley & Moxon, 1938; Munsell, et. al., 1936; Rosenfeld & Beath, 1947).

The selenium tolerance of animals is complicated by other components of their diets. High protein levels and linseed oil meal both afford effective protection against selenosis in rats (Martin, 1973). Vitamin E also may act to reduce their selenosis incidence (Witting and Horwitt, 1964). Sulfate supplements relieve growth depression caused by selenium excess,

but are fairly ineffective in reducing liver degeneration. The most effective dietary factor in reducing selenium toxicity is arsenic. Moxon (1938) showed that 5 ppm arsenic in drinking water prevented all signs of selenosis in rats. Arsenic, as sodium arsenite and sodium arsenate, has since been successfully used to alleviate selenium poisoning in pigs, dogs, chicks and cattle (Underwood, 1971).

Selenium in elevated concentrations is damaging to aquatic life; concentrations of 2.0 mg/l have been demonstrated to be lethal to goldfish in 18 to 46 days (Ohio River Valley Water Sanitation Commission, 1950), and concentrations as low as .25 mg/l cause behavioral impairment (Weir and Hine, 1970). Bringman and Kuhn (1959) demonstrated the existence of a median threshold effect in a 48-hour period of 2.5 mg/l for the freshwater crustacean, Daphnia, and 183 mg/l for the protozoan, Microregma. Cardwell et al. (1976) conducted acute toxicity tests of selenium dioxide on six species of freshwater fish. The results indicate that SeO_2 is most toxic to fathead minnows and least toxic to bluegill. The decreasing order of sensitivity was: fathead minnow, flagfish, brook trout, channel catfish, goldfish and bluegill. The 96-hour LC50 estimates ranged from 2.9 mg/l SeO_2 (2.06 mg/l Se) for fathead minnow fry to 40.0 mg/l (28.4 mg/l Se) for bluegill juveniles. LC50 values for selenium dioxide at different exposure periods are shown in Table 4.5.1 for bluegill, the common Illinois test species. Values in mg/l SeO_2 are converted to mg/l Se for reference to Illinois standards.

Aquatic plants also appear to be capable of being adversely affected by elevated selenium concentrations. Sielicki and Burnham (1973) demonstrated that algae undergo physiological and morphological changes in waters containing as little as .079 mg/l (10^{-6}M) of selenium. Chau and Wong (1977) concluded that,

TABLE 4.5.1

MEDIAN LETHAL CONCENTRATIONS OF SELENIUM DIOXIDE FOR THE BLUEGILL

(Lepomis machrochirus Refinesque)

Exposure Time (hours)	*LC50-SeO_2 (mg/l)	LC50-Se** (mg/l)
8	126.6	89.9
18	82.1	58.3
24	77.3	54.9
168	30.7	21.8
192	27.7	19.6
240	23.6	16.8
288	20.5	14.5
336	17.6	12.5

*LC50 = Concentration that kills 50% of the test specimen population in the given time periods.

**LC50-Se = Calculated using ratio of atomic weights (Se/SeO_2).

Compiled from Cardwell et. al., 1976.

due to bioaccumulation of selenium by zooplankton and a low selenium safety factor (ratio of toxic rate to normal ingestion rate), selenium is a potentially dangerous aquatic chemical. Safety factors are estimated to be 25 for selenium, versus 50 to 500 for arsenic, and 500-2000 for mercury.

Chronic selenium toxicity has been described in humans. However, it is neither common nor are its symptoms well defined. Dietary human selenosis tends to occur only when selenium intake levels are consistently above 5 ppm in solid foods and .05 mg/l in liquids (Shapiro, 1973). Several cases of suspected dietary selenium poisoning have been reported from seleniferous areas of the western U.S. Common ailments included dizziness, fatigue, dermatitis, nail changes and edema. In some cases, elimination of dietary selenium relieved the symptoms. In one severe case, bromobenzene, which increases urinary excretion of selenium, was administered and all symptoms disappeared rapidly (Moxon, et. al. 1940).

Water supplies seldom contain sufficient selenium to be considered hazardous, even in seleniferous regions (Olson, 1969). However, there are exceptions. In one case, a family in Colorado developed toxicity symptoms after using, for 3 months, well water which contained 9 mg/l of selenium (Beath, 1962).

In addition to dietary intake, selenium poisoning can occur in humans due to exposure of selenium to the skin and inhalation of seleniferous fumes or dust. Symptoms include burns, mucosal irritation, wheezing, chemical pneumonitis and pulmonary edema. However, no evidence has shown any clear, long-term systemic effects of contact with selenium among workers in industries which use large amounts of the element. Holmquist (1969) has concluded that no serious health problems are caused by industrial selenium when hygenic standards are strictly maintained.

Selenium has been variously implicated as a carcinogenic and anticarcinogenic agent. Nelson et. al. (1943) reported that low-grade cancerous tumors occurred in rats fed diets containing 5-10 ppm. On the basis of similar limited studies, selenium was listed as a carcinogen in the Food Additive Amendment of 1958 to the Food, Drug and Cosmetic Act (Shapiro, 1973). Shamberger and Frost (1969) disputed this designation on the basis of their study of human cancer death rates, in which they obtained an almost perfect inverse relationship ($r = -0.96$) between selenium levels in blood and cancer death rates in a sample of 10 cities with populations of 40,000 to 70,000. Other studies have shown similar inverse relationships between cancer rates and selenium levels in milk and locally grown plants (Frost, 1977).

4.6 Summary of Health Effects of Selenium

A simple summary of the health effects of environmental selenium remains a matter of controversy. On one extreme, Frost (1977) summarized the nutrient and disease-prevention aspects of selenium and concluded that "selenium deficiency is thought to represent far more of a problem than are any likely excesses of Se in the environment. Realistically, then, Se should be viewed not as a pollutant, but as a critically essential nutrient" (p. 594).

On the other extreme Chau and Wong (1977) have argued that the evidence for selenium toxicity is so compelling that in spite of the known nutritional aspects of the element, it must continue to be considered a hazardous pollutant.

Chapter 5

SELENIUM STANDARDS AND GUIDELINES

5.1 Introduction

Standards and guidelines covering selenium in waters have been promulgated by a range of agencies and for a range of water types and uses. This chapter reviews the status of such standards, particularly as they are applied in the U.S.

5.2 Drinking Water Standards

In 1961 the World Health Organization set the "excessive limit" for selenium at .05 mg/l in its European Standards for Drinking Water. In 1962 the Public Health Service of the U.S. Department of Health, Education and Welfare lowered this value to .01 mg/l for U.S. drinking water. The lower value has since been reaffirmed in the report of the National Technical Advisory Committee to the Secretary of the Interior (1968), the Safe Drinking Water Act of 1974, and by the U.S. Environmental Protection Agency (1973, 1976).

5.3 Surface Water Standards

Standards for selenium in surface water have been promulgated in several forms. A common form is the narrative standard which states that no toxic substance may be present in concentrations which adversely impact the environment. Selenium is never specified by name in such statements, but implicitly included to the extent that it may be considered a toxicant. Most states use this type of narrative standard (Table 5.3.1), which is typified by that of Alabama:

TABLE 5.3.1

SURFACE WATER QUALITY STANDARDS FOR SELENIUM, BY STATE

(Compiled from Patterson, 1977, and Herricks, 1977).

State	Standard	Water Use Classification*
Alabama	Narrative	GU/PWS
Alaska	Narrative	GU/PWS
Arizona	.01 mg/l PWS; Narrative, GU	GU/PWS
Arkansas	.01 of 96 hr median Toxic Limit	GU/PWS
California	.01 mg/l; (.05 livestonck; .02 irrig.)	PWS
Colorado	Narrative	GU
Connecticut	Narrative	GU/PWS
Delaware	Narrative	GU
Florida	Narrative	GU/PWS
Georgia	Narrative	GU/PWS
Hawaii	Narrative	GU/PWS
Idaho	Narrative	GU
Illinois	1.0 mg/l, GU; .01 mg/l, PWS	GU/PWS
Indiana	Narrative	PWS
Iowa	1.0 mg/l, GU; .01 mg/l, PWS	GU/PWS
Kansas	Narrative	GU/PWS
Kentucky	.01 mg/l	PWS
Louisiana	Narrative	GU
Maine	Narrative	GU/PWS
Maryland	None	
Massachusetts	Narrative	GU/PWS
Michigan	Narrative	GU
Minnesota	.01 mg/l	PWS/I
Mississippi	.01 mg/l	PWS/GU
Missouri	Narrative	GU/PWS
Montana	Narrative	GU/PWS/I
Nebraska	Narrative	GU/PWS
Nevada	Narrative	GU/PWS
New Hampshire	Narrative	GU/PWS
New Jersey	.01 mg/l and Narrative	GU/PWS/I
New Mexico	Narrative	VAR
New York	Narrative	GU
North Carolina	Narrative	GU/PWS
North Dakota	.01 mg/l	GU/PWS
Ohio	.005 mg/l	GU/PWS/I
Oklahoma	Narrative	GU/PWS/I

TABLE 5.3.1

(con't)

State	Standard	Water Use Classification*
Oregon	Narrative	VAR
Pennsylvania	Narrative	VAR
Rhode Island	Narrative	GU/PWS/I
South Carolina	Narrative	GU/PWS/I
South Dakota	None	VAR
Tennessee	Narrative	GU/PWS/I
Texas	Narrative	GU/PWS
Utah	Narrative	GU/PWS/I
Vermont	Narrative	GU/PWS
Virginia	.01 mg/l	GU/PWS
Washington	Narrative	GU/PWS/I
West Virginia	.01 mg/l and Narrative	GU/PWS
Wisconsin	Narrative	GU/PWS
Wyoming	Narrative	GU/PWS

*GU: General Use
PWS: Public Water Supply
VAR: Standards vary with water body
I: Industrial Uses

Toxic substances... or other deleterious substances attributable to sewage, industrial wastes or other wastes:

Only such amounts, whether alone or in combination with other substances or waste, as will not: render the water unsafe or unsuitable for swimming and water contact sports; be injurious to fish, wildlife and aquatic life or impair the waters for any other usage established for this classification or unreasonably affect the aesthetic value of waters for any use under this classification. (Patterson, 1977, p. D-3)

Other commonly used narrative forms expressing standards for toxic substances or "chemical constituents" are: "none in harmful levels", or "none to exceed USPHS drinking water standards...after adequate treatment". The latter infers numerical values.

Only a few states, Illinois included, utilize specific numeric standards for selenium (Table 5.3.1). The most common numeric value is .01 mg/l, the same maximum concentration allowed by Federal Law in finished drinking water (section 5.2). The two states (Illinois and Iowa) which both use numeric standards and distinguish public water supply use from general use, limit selenium at 1.0 mg/l in the general use category (Table 5.3.1). California specifies separate numeric standards for water used for irrigation (.02 mg/l) and for livestock (.05 mg/l). These are based on U.S. EPA guidelines published in U.S. Environmental Protection Agency (1973).

5.4 Effluent Standards

Only two states, Illinois (1.0 mg/l) and Delaware (.020 mg/l) have specified numeric standards for selenium in effluent (Patterson, 1977); Connecticut uses a standard based on best available technology (BAT). Such control on seleniferous effluents as is exerted by other states is through

standards applicable to waters receiving the effluent or through Federal effluent guidelines.

5.5 U.S. EPA Effluent Limitations Guidelines

Under authority of Public Law 92-500 (an Act to Amend the Federal Water Pollution Control Act), the U.S. Environmental Protection Agency has promulgated effluent guidelines to be met on an industry by industry basis. The guidelines were developed to reflect the application of both Best Practicable Control Technology Currently Available (BPCTCA) and Best Available Technology Economically Achieveable (BATEA). As promulgated, the guidelines are expressed in mass discharge units. These units have been converted to concentrations by Patterson (1977).

The guidelines deal only with anticipated major pollutants. Selenium is considered to be such in only four (Table 5.4.1) out of a total of more than 400 industrial subcategories (Patterson, 1977). Of the four subcategories, only one, Primary Zinc, is known to be represented in Illinois, and that, by only a single plant which does not have an independent effluent discharge (section 3.15). Among the subcategories for which no selenium guidelines were set are many which are known or suspected (sections 3.13-3.15) to produce low-concentration seleniferous effluents.

5.6 Illinois Selenium Standards, Present and Proposed

Under present regulations, Illinois has three specific numerical standards for selenium, plus four narrative rules which can be construed to include selenium (Table 5.6.1).

TABLE 5.5.1

U.S. EPA INDUSTRIAL EFFLUENT GUIDELINES FOR SELENIUM, MG/L.

Catagory	Subcatagory	BPCTCA Avg.*	BPCTCA Max.**	BATEA Avg.*	BATEA Max.**
Inorganic Chemical	Copper Sulfate 40 CFR 415.360	0.5	1.6	nd	nd
Nonferrous Metals	Primary Copper Smelting 40 CFR 421.40	5.0	10.0	5.0	10.0
Nonferrous Metals	Primary Copper Refining 40 CFR 421.50	5.0	10.0	5.0	10.0
Nonferrous Metals	Primary Zinc 40 CFR 421.80	5.0	10.0	5.0	10.0

*Thirty-day average, in mg/l.

**Twenty-four hour maximum, in mg/l.

nd: no data

TABLE 5.6.1

CURRENT ILLINOIS WATER QUALITY RULES WHICH IMPLICITLY OR EXPLICITLY REGULATE SELENIUM CONCENTRATIONS (Compiled from Illinois Pollution Control Board, 1976).

Water Type	IPCB Rule	Standard
All Water Unless Specifically Exempted	203(a)	Freedom from...matter in concentrations or combinations toxic or harmful to human, animal, plant or aquatic life of other than natural origin.
General Use	203(f)	1.0 mg/l
General Use	203(h)	Any substance toxic to aquatic life shall not exceed one-tenth of the 48-hour median tolerance limit (48-hr TLm) for native fish or essential fish food organisms.
Public and Food Processing Water Supply	204(b)	0.01 mg/l
Restricted Use	205(e)	Concentrations of other substances shall not exceed the applicable effluent standards prescribed in Part IV.**
Effluent	402	...no effluent shall, alone or in combination with other sources, cause a violation of any applicable water quality standard.
Effluent	408(a)	1.0 mg/l

**1.0 mg/l by rule.408(a)

Under the proposal that "selenium be deleted as a parameter to be regulated under Rule 408, and that it be regulated only under the Illinois Water Quality Standards and the U.S. EPA Effluent Limitation Guidelines" (Illinois Effluent Standards Advisory Group, 1976, p. 20), specific numeric limitations on selenium in effluents would be eliminated. Little effect would derive from the U.S. EPA Effluent Limitation Guidelines system, since selenium is included in only a limited number of industrial subcategories, of which there are no known independent outfalls in Illinois (sections 5.5 and 3.15). Moreover, it is unlikely that new operations in these subcategories will locate in Illinois in the foreseeable future, since each requires a raw material which is either not present or present only in limited quantities in the state. The possibility does remain that the Guidelines will be amended and revised in time such as to include selenium limitations on other industries, some of which may exist now or in the future in Illinois.

In the absence of the Rule 408 provision for selenium concentrations in effluent, the only remaining state-level control on seleniferous discharges would be through Rule 402. Rule 402 limits effluents which cause violation of any other water quality standard (Table 5.6.1).

Elimination of the Rule 408 provision would apparently also eliminate the current 1.0 mg/l standard for restricted use waters (Secondary Contact and Indigenous Aquatic Life Waters), which derives from Rule 408 via Rule 205-e (Table 5.6.1).

Chapter 6

PERFORMANCE TO REGULATIONS

6.1 Illinois Surface Waters

Selenium displays one of the lowest rates of violation exhibited by any of the constituents for which standards exist. Only .06% of all selenium analyses have exceeded the .01 mg/l Illinois Public Water Supply standard (Table 6.1.1), and .01% have exceeded the more restrictive livestock water supply standard; there are no recorded incidences of violation of the 1.0 mg/l Illinois General Use standard.

Incidence of detectable selenium in Illinois surface waters is similarly low (section 3.10). Of 764 ambient water quality stations operating between 1972 and 1976, aggregating a total of 7822 selenium analyses, only 16 stations produced a detectable selenium reading (Table 3.10.1). Fifteen of the sixteen produced only a single detectable reading; the remaining station, BF 01, on Sugar Creek-South near Palestine, produced 6 of the total of 21 detectable readings. This station is located downstream from the most significant selenium effluent discharge in Illinois (sections 6.2 and 6.3). The Sugar Creek-South station was also responsible for 4 of the 5 Public Water Supply violations (Table 3.10.1).

6.2 Illinois Effluent Discharges

There is only one recorded incidence of violation of the current Illinois effluent standard for selenium (Table 6.1.1). This occurred in the discharge of Marathan Oil Company, Robinson, on June 24, 1975 (Table 3.15.3).

It should be noted, however, that the record of selenium monitoring of effluent discharges is not extensive. As of December 1976, the IEPA had on file a total of 65,997 analyses of effluent discharges made at a total of 2391 points. Selenium analyses were made on only 2172 (3.3%) of the samples

TABLE 6.1.1

INCIDENCE OF VIOLATION OF SELENIUM STANDARDS IN ILLINOIS (Compiled From IEPA files).

Standard		Ratio	Percent
Surface Water Standards:			
Public Water Supply	.01 mg/l	5:7822	0.06
Livestock Water Supply	.05 mg/l	1:7822	.01
General Use	1.0 mg/l	0:7822	.00
Effluent Standard	1.0 mg/l	1:2172	.05

at 868 (36.3%) of the points. Many of the points had only a single analysis, and many of the unsampled and excluded points are sources which might logically be expected to produce seleniferous wastes (section 3.15).

6.3 Marathon Oil Company/Robinson and Sugar Creek-South

Although Marathon Oil Company/Robinson cannot be considered a serious violator of the selenium effluent standard, it nevertheless has a poorer record of selenium effluent discharges than does any other known discharger in Illinois. Similarly, although Sugar Creek-South, the stream to which Marathon discharges, has only a moderate level of standards violations, it nevertheless has the highest incidence of selenium among all monitored streams in Illinois. A cause and effect relationship between Marathon's seleniferous discharges and the shows of selenium in Sugar Creek-South seems plausible.

Information given by Marathon Oil indicates that selenium is not added as a cracking catalyst or oxidant in their refining processes. They believe it must therefore occur naturally in their crude oils. Marathon noted that the selenium shows seem to be intermittent. This could be attributed to the fact that they refine crude oils from many different sources, including foreign oil and oil from throughout the U.S., as well as from their Robinson fields, each of which may contain selenium in differing concentrations. However, the association of recovery of elemental sulfur with seleniferous effluent noted in section 3.15 implies that it is this operation rather than refining per se which produces the seleniferous wastes. Marathon currently employs no waste treatment process specifically designed to remove selenium from effluent, nor does it use any of the advanced treatment methods which affect removal of selenium incidental to removal of other materials.

The IEPA conducted a biological survey of macro-invertebrates on Sugar Creek-South in 1974, at a location near the ambient water quality monitoring station and approximately seven miles downstream from Marathon's discharge point. On the basis of a dominance of pollution-tolerant species, the stream at that point was classified as "semi-polluted". This classification is in general agreement with evaluations made on the basis of the IEPA's four parameter water quality index (Illinois Environmental Protection Agency, 1977) which classified the waters at the station as "semi-polluted" based on samples from the years 1973 and 1974 and as "average" based on samples from the years 1972 and 1975; these are the only years for which indices are available. Among a total of 55 ambient water quality stations in the Wabash River basin, the station on Sugar Creek-South was the only station that warranted "semi-polluted" classification in more than one year of the index calculations, and one of only three stations that failed to warrant "good" classification in at least one year.

The generally poor biological condition of Sugar Creek-South was confirmed in an independent survey conducted for this report (Appendix A). The principal conclusions of this survey are:

1. The stream which receives Marathon's effluent (unnamed tributary to to Sugar Creek-South) is adversely impacted above Marathon's outfall point, apparently by effluent from Robinson Sewage Treatment Works.
2. Impact of Marathon's effluent is most pronounced at and downstream from the outfall point; in these portions no evidence of instream animal life was found, nor were any signs of use of the stream by terrestrial vertebrates.

3. Although Marathon's refinery effluent does have an apparently strong and adverse impact on the Sugar Creek-South system, nothing can be said about the specific impact--if any--of the selenium concentrations in the effluent.

Even though the water quality of Sugar Creek-South is less than ideal, there is no basis for attributing the deteriorated quality solely to excesses of selenium. Standards for chemical constituents other than selenium have been violated with regularity (Table 6.3.1), such that the deteriorated quality may be readily attributable to these other constituents.

Similarly, there is no basis for attributing the deteriorated quality of Sugar Creek-South solely to Marathon Oil. Marathon Oil is one of six known point source dischargers located upstream from the Sugar Creek-South water quality station, each of which have records of violation of one or more of the general use standards (although not necessarily of the effluent standards) listed in table 6.3.1.

TABLE 6.3.1

RECORD OF VIOLATIONS OF ILLINOIS SURFACE WATER STANDARDS, SUGAR CREEK-SOUTH, Station BF-01

Constituent	No. of Samples	General Use Standard Violations	Public Water Supply Standard Violations
Ammonia Nitrogen	57	22	22
Boron	13	2	2
Cadmium	15	0	3
Chloride	15	2	9
Chromium, hexavalent	14	4	*
Copper	15	7	7
Cyanide	14	1	1
Dissolved Oxygen	56	4	4
Fecal Coliform	57	52	52
Fluoride	15	6	6
Iron, total	15	2	8
Manganese	15	2	15
Mercury	19	1	1
Methyl Blue Actives	36	*	32
Nitrate Nitrogen	57	*	1
Phenols	40	1	39
Selenium	13	0	4
Silver	13	2	2
Sulfate	15	1	8
Total Dissolved Solids	40	12	28

*No standard

No violations for Arsenic, Barium, trivalent Chromium, Nickel, Lead, pH and Zinc.

Chapter 7

WASTEWATER TREATMENT TECHNOLOGY AND COSTS

7.1 Summary of Current Technology

Patterson (1976) summarized the status of current technology for the removal of selenium from wastewater. Patterson's conclusions are:

1. Most treatment processes investigated for the control of selenium have shown to be ineffective.
2. The commonly employed industrial metal treatment processes (e.g., lime coagulation, settling and sand filtration) are ineffective in recovering selenium, at least as the negatively charged ions, selenite and selenate.
3. Efforts to remove selenium through standard filtration, sedimentation, chlorination, and activated carbon absorption processes have produced some mixed results, but have been unsuccessful for the most part.
4. Among tested coagulation techniques, only ferric sulfate coagulation has produced selenium removal at levels in excess of 75%.
5. The single most successful technique known for the removal of selenium is a strong acid-weak base cation-anion exchange system, which in combination with sand filtration and activated carbon absorption has been shown to effect 99.9 percent removal in bench-scale tests. The process is non-selective for selenium.

7.2 Status of Treatment for Selenium in Illinois

There are no known wastewater treatment works in Illinois which employ any treatment process specifically designed to reduce or remove selenium in any effluent. This includes all dischargers with records of seleniferous

effluent (section 3.15). It does not include removal which might be effected incidentally by processes designed for control of other substances.

7.3 Treatment Costs

Assessment of the cost of selenium treatment systems is difficult because there are so few systems specifically designed to control selenium in wastewater, and much of the control which is exercised is accomplished incidentally to control of other substances.

Assessment may be made under the assumption that the selenium content of wastewater is sufficient to require an ion-exchange system. Costs of ion-exchange are generally much higher than those of conventional treatment systems. Examples for several plant sizes and two feedwater conditions are given in Table 7.3.1. Except for very small plants or very low total dissolved solids in the feedwater, costs are dominated by cost of chemicals. Since ion-exchange is non-selective for selenium and thus effects simultaneous removal of other constituents, it may not be proper to assign full costs of the system solely to selenium treatment.

TABLE 7.3.1

ESTIMATED DAILY COSTS OF AN ION-EXCHANGE TREATMENT SYSTEM FOR PLANTS OF FOUR DIFFERENT SIZES AND TWO FEEDWATER CONDITIONS (Compiled from Ahlgren, 1969, without allowances for inflationary cost increases).

Plant Size (MGD)	Feedwater TDS = 100 mg/l* Daily Cost in $			Feedwater TDS = 1000 mg/l* Daily Cost in $		
	Chemical	Amortization	Total	Chemical	Amortization	Total
0.01	1	2.5	3.5	10	3.5	13.5
0.1	10	15	25	100	25	125
1.0	100	80	180	1,000	180	1,180
10.0	1,000	500	1,500	10,000	1,500	11,500

*Total Dissolved Solids as $CaCO_3$

Chapter 8

COST/BENEFIT CONSIDERATIONS

8.1 Introduction

Cost/benefit analysis of the proposed change in the Illinois selenium effluent standard offers several unusual facets. These stem from two basic conditions. The first is that no effluent dischargers in Illinois are known to have taken any action to reduce selenium in their effluents. The second is that the proposed change involves a lessening of regulation via elimination of a standard. The result of these two conditions is that the proposed standard change has few tangible costs or benefits.

8.2 Effect of the "No Action" Condition

To the best knowledge of the authors and of the IEPA (J. Parks, personal communication, 1977), no discharger within the state of Illinois employs any wastewater treatment process specifically intended to reduce or remove selenium from effluent, or to otherwise effect compliance with the current selenium effluent standard. Also, no discharger within the state has had any action taken against it to require such treatment. Both conditions stem from the low incidence of selenium in virtually all effluents known in Illinois (section 3.15 and 6.2).

Because no action has derived from compliance with the Rule 408 selenium standard, no tangible costs have been associated with its existence other than those which are associated with administering the standard. Similarly, "no action" has caused no tangible benefits to accrue from the standard other than those associated with administering it.

Administrative costs and benefits are comparatively minor. Costs include salaries and wages and equipment costs associated with monitoring, analyzing,

data manipulation, and otherwise administering the standard. Benefits are largely those which accrue to the manufacturer and seller of selenium testing chemicals and/or equipment, to salaried employees involved in the administration, and possibly the public assurance that selenium is not being discharged at harmful levels.

8.3 Effect of "Deregulation" Condition

Elimination of the Rule 408 selenium standard would have the general effect of lessening--but not eliminating--restrictions currently applied to seleniferous effluent. Since no discharger has had to incur tangible costs associated with meeting the current, more restrictive standard, no tangible costs to the discharger can be assumed to derive from meeting the less restrictive conditions.

Neither is it likely that tangible costs to the environment would result from deregulation. Under the combined provisions of Illinois Pollution Control Board Rules 203-f, 402-b and 402, the Illinois EPA will continue to monitor and enforce water quality standards 1.0 mg/l for General Use waters and 0.01 mg/l for Public and Food Processing Water Supplies. Except for Restricted Use waters, surface waters of the state would be subject to no greater selenium levels than allowed under current regulations. Any evidence of harmful discharges of selenium would be picked up during routine water quality monitoring. Corrective action could be taken under the water quality regulations.

It is impossible to know for certain whether any industries are being kept out of the state due to the existence of the Rule 408 selenium standard, and that they would subsequently locate in the state if the standard were

eliminated. However, the evidence does not support this assumption. Similarly, it is unlikely that anyone in the state is foregoing manufacture of a certain product due to the selenium standard. In both cases, the industries recognized by the U.S. EPA Effluent Limitation Guidelines (section 5.5) as having the potential for producing high-selenium wastewater either require proximity to raw materials which are not present in Illinois, or, as in the case of the single Primary Zinc smelter, have apparently not found difficulty in complying with the current regulation (section 3.15). Also, in both cases, the industry would still be subject to selenium limitation depending upon the classification of the receiving water body.

Another possible situation is that somebody in the state is treating for selenium unknown to the IEPA, and that with removal of the standard they might dump significantly higher levels of the substance. However, this seems most unlikely, since the only reason they would be treating in the first place is if their effluent concentrations were over 1.0 mg/l, and the elaborate treatment equipment necessary to reduce such high levels to inconspicuously low levels ought to be well known to IEPA officials. In any eventuality, excessive discharges could not be released such as to cause Rule 402 violations.

A possible cost item associated with deregulation is cost associated with added enforcement of Rule 402. In the eventuality that a water body is found to contain selenium in excess of its appropriate standard, a monitoring program would have to be initiated to locate the specific effluent source responsible for the violation. Since the monitoring program would require time for its implementation, it is possible that there may be an additional cost associated with environmental deterioration accruing during the investigative

period, that would not occur if the current continuous monitoring of all effluents was continued. Costs associated with this situation are so highly variable that no attempt can be made to adequately project them.

8.4 Intangible Costs and Benefits

In the absence of significant tangible costs and benefits, intangible costs and benefits become relatively important. The principal such item is the good will of both industry and the citizenry of the state. Good will may be expected to derive from these quarters if it is seen that a regulation is deleted which can be viewed to be ineffective, producing no benefits, and possibly unachievable in circumstances where it would be applicable. However, it may be expected that there would be a second element which would see deregulation negatively in the view that any lessening of environmental standards is an inappropriate step.

8.5 Cost/Benefit Summary

There are no major tangible costs or benefits which derive from the existing selenium standard of Rule 408. Similarly, there are no major tangible costs or benefits which could be expected to accrue from elimination of the standard. The only such costs and benefits relate to the administration of the standard. Under these conditions, the element of good will between government and citizenry becomes the salient cost/benefit item.

APPENDIX A

FIELD OBSERVATIONS OF THE EFFECTS OF MARATHON OIL REFINERY EFFLUENT ON THE SUGAR CREEK-SOUTH SYSTEM

Field observations were made on Friday, July 8, 1977, by D.C. Wilkin and his assistant, Sue Hebel, both trained biologists, on the effects of the Marathon Oil Refinery discharge on receiving waters near Robinson, Illinois. Observations were made of general water characteristics, instream biota, and streamside biota. The following were noted.

General: The outfall delivers to an unnamed tributary to Sugar Creek in the northeast quarter of section 35, Township 7 North, Range 12 West. Above the outfall, the only flow in this stream seems to be sewage effluent from the Robinson Municipal Sewage Disposal facility. At the point of the outfall, the municipal sewage flow has travelled about a mile from the treatment plant. The effluent from the refinery has, itself, travelled nearly a mile underground in a pipe. Above the outfall,the stream is characteristic of sewage-effluent contaminated streams, with substantial algal growth, a moderate odor, and a variety of organisms including sludge worms attached to the rocks. From the outfall, all the way to the IEPA monitoring station near Palestine, roughly 6 or 7 miles, the stream character is dominated by the refinery effluent. At its point of entry, it is orange-brown, highly turbid, warm and has a strong petrochemical odor. For three or more miles downstream, no evidence of instream animal life forms was found, nor were any signs of use of the stream by terrestrial vertebrates. A green slime alga covering a black slime layer covered many of the rocks. The odor remained strong throughout the area surveyed. Gradually, larval cases and tubificid worms reappeared, as well as tracks of terrestrial vertebrates at streamside.

Specific Notes:

First Location: 1/10 mile above Marathon outfall, on unnamed tributary to Sugar Creek. A typical sewage effluent-dominated stream with streaming webbed algae abundant. Tubifex worms and small snails were under and on the rocks. Raccoon tracks were observed at streamside, along with small dog or dog-like tracks, right next to the water. Streamside vegetation and bird life appeared normal.

Second Location: Immediately below Marathon outfall. Volume of effluent flow appeared to be 1-1/2 to 2 times the flow from the sewage treatment plant. Discharge was orange, highly turbid, warmer than ambient, with a strong petrochemical odor. A water-soluble black muck was found below the sand at the periphery of the stream. No signs of instream animal life could be found. A slimy green-colored alga covering a black slime layer coated many of the rocks. Raccoon tracks were observed in the dry area of the stream bed, but not near the water. Streamside vegetation and bird life appeared normal.

Third Location: Road crossing, roughly 1-1/4 stream miles below the outfall. Water was orange-colored, somewhat less turbid, but still warmer than ambient. No instream animal life could be found, but a water strider was observed on the surface under the bridge. The green and black slime alga still present on rocks. Odor remained strong.

Fourth Location: Township road crossing, roughly 2-1/4 miles below outfall. A probable channelized section. Water was deep, slow moving and turbid. Odor remained.

Fifth Location: East-west road crossing, roughly 3-1/2 miles downstream from outfall. A slow moving channelized area. Odor remained, and temperature was approximately ambient. Some larval cases and a few worms were observed. The green and black slime alga was present.

Sixth Location: Junction of unnamed tributary with Sugar Creek. Both tributaries are channelized at this point. There was no flow in Sugar Creek, only backwater from the tributary. A strong odor remained. In the backwater, floating green algal mats were present, but not dominant. Water was orange colored, but clear. Rocks had some green and black slime algae. A dark green alga was found in quiet waters. Many terrestrial vertebrate tracks were found at immediate streamside, many tubifex worms and larval cases were found on the rocks.

Seventh Location: Township road bridge, northeast of Palestine, near Illinois Central Railroad bridge. The odor remained as well as the color. The black and green slime algae still present. Many tubificid worms, and larval cases found. Hunks of coal were found in the stream. A local resident reported no fishing in stream above here, but that some is done downstream before it enters the Wabash. Animal tracks were found down to streamside.

Conclusions: Nothing can be said about selenium from these observations, although the refinery effluent does have a strong and adverse impact on the receiving stream. The characteristics of the effluent dominate the stream from the outfall down to the IEPA sampling station, some six or seven miles away. It may be significant, however, that fishing is reported in the stream above where it enters the Wabash, since a substantial part of the flow at that point derives from the refinery. While the effluent is clearly inimical to "clean" stream biota, such effects could as easily derive from the high temperature/low dissolved oxygen observed. No significant impact can be discerned regarding the effect of stream water quality on streamside vegetation or wildlife. More information will be necessary on the character of the effluent before the effects of selenium, if any, can be separated.

ASSESSMENT WORKSHEET
CROSS-CHECKLIST FOR BENEFIT CONSIDERATIONS
economic impact study

ALTERNATIVE ASSESSED Deregulation

DESCRIPTION Elimination of the current selenium effluent standard

REGULATION NO. _____ IIEQ PROJECT NO. 80-092 TITLE: Economic Impact of the Selenium Effluent Standard in Illinois

BENEFIT CATEGORIES	LEVEL OF INFORMATION: QUALITATIVE BENEFIT ASSESSMENT	REFERENCE	QUANTITATIVE BENEFIT ASSESSMENT: Amount of Benefit	Units of Measure	Range of Benefit Uncertainty	$ Value	Range of $ Uncertainty	EXPLANATORY REMARKS
1. Health	Some studies indicate that selenium is a cancer preventative	72,73						Studies showed an inverse relationship between human blood selenium levels and occurrence of cancer in ten cities.
	Cardiovascular and various other chronic diseases may have selenium deficiency as an underlying cause	20						
	Selenium appears to be necessary for full recovery from the protein deficiency disease, kwashiorkor	7						Blood Selenium levels increase as recovery proceeds.
	Selenium is a natural antidote for certain heavy metal poisonings.							Selenium has been shown to reduce toxic effects of mercury, cadmium aresenic, and methylmercury.
	No serious health hazards are caused by industrial selenium when hygenic standards are strictly maintained	25,26						
2. Natural Environment A. Livestock	Selenium deficiency is an underlying cause in several livestock diseases.	38,68, 83						e.g. stiff lamb disease, white muscle disease, infertility, unthriftiness, liver necrosis, hepatosis dietetica, and hair loss.
B. Poultry	Selenium deficiency in chicks causes exudative diathesis, poor growht and feathering, and pancreatic degeneration.	80,81, 68						

BENEFIT CATEGORIES	LEVEL OF INFORMATION							EXPLANATORY REMARKS
	QUALITATIVE BENEFIT ASSESSMENT	REFERENCE	QUANTITATIVE BENEFIT ASSESSMENT					
			Amount of Benefit	Units of Measure	Range of Benefit Uncertainty	$ Value	Range of $ Uncertainty	
C. Laboratory Animals	Several diseases result from selenium deficiency in laboratory controlled experiments.	68						e.g. Reproductive failure, ailments of liver, blood, brain, capillaries, and pancreas, and nutritional myopathies; also complicated by vitamin E deficiency.
3. Recreational	None							
4. Aesthetic & Human Interest								
5. Industrial/Commercial	The only treatment process that effectively removes selenium is very expensive and non-selective.	1,59						Strong acid-weak base ion exchange.
6. Agriculture	More losses, in more areas, have occurred from selenium deficiency than from excess.							
	Indeficient areas, selenium must be supplemented in poultry and swine feed.	85	to .1ppm and to .2ppm feed	in chicken swine feed in turkey				
7. Structural	None							
8. Governmental	Any costs associated with administering and enforcing the standard would be eliminated.							

ASSESSMENT WORKSHEET
CROSS-CHECKLIST FOR BENEFIT CONSIDERATIONS
economic impact study

ALTERNATIVE ASSESSED Status Quo

DESCRIPTION Benefits of keeping the current selenium effluent standard

REGULATION NO. _____ IIEQ PROJECT NO. 80.092 TITLE: Economic Impact of the Selenium Effluent Standard in Illinois

BENEFIT CATEGORIES	LEVEL OF INFORMATION							EXPLANATORY REMARKS
	QUALITATIVE BENEFIT ASSESSMENT	REFERENCE	QUANTITATIVE BENEFIT ASSESSMENT					
			Amount of Benefit	Units of Measure	Range of Benefit Uncertainty	$ Value	Range of $ Uncertainty	
1. Health	Some studies have found selenium to be carcinogenic	54,75			Large			Low grade tumors in laboratory rats caused selenium to be listed as a carcinogen.
	Excess dietary intake of Selenium causes toxicity symptoms such as dizziness, fatigue, dermatitis, nail changes, and edema.	74,51 75		5 ppm in Solids .05 mg/l in liquids				When dietary intake is consistently above these limits.
	Industrial selenosis occurs with external exposure to or inhalation of selenium. Symptoms include burns, mucosal irritation, chemical pneumonitis, and pulmonary edema.	74						Not a problem when hygiene standards are strictly maintained (Holmquist, 1969).
2. Natural Environment A. Animals 1. Livestock	Selenium excess causes toxicity diseases such as "alkali disease" and blind staggers" in seleniferous areas.	46,65, 83 75						
2. Poultry	Excess selenium causes embryonic abnormalities leading to reduced hatchability in chicks.	19,62	@ 5ppm					In Illinois, selenium is added as a supplement to poultry and swine feeds.
3. Laboratory Animals	Anemia and liver changes in rats and dogs, and	50,52	@ 5-10ppm					
	Disease symptoms in young pigs fed seleniferous diets.	64	@ 5-10ppm					
4. Aquatic Animals	Behavioral impairment occurs in goldfish at sublethal concentrations.	90		.25 mg/l				

BENEFIT CATEGORIES	LEVEL OF INFORMATION							EXPLANATORY REMARKS
	QUALITATIVE BENEFIT ASSESSMENT	REFERENCE	QUANTITATIVE BENEFIT ASSESSMENT					
			Amount of Benefit	Units of Measure	Range of Benefit Uncertainty	$ Value	Range of $ Uncertainty	
	Extended exposure to toxic concentrations of selenium is lethatal to goldfish.	57,17		2.0 mg/l				
	96-hour LC_{50} varies with species fathead minnowfry-most sensitive blue gill juveniles-least sensitive.	42		2.9 mg/l 40.0 mg/l				Species tested: fathead minnow, flagfish, brook trout, channel catfish, goldfish, & bluegill. External hemorrhaging or lesions occurred in fathead minnow, brooktrout, channel catfish, & goldfish.
	Wide variation in sensitivity is shown in other aquatic animals: 48 hr.-Median threshold effect for freshwater crustacean, Daphnia, vs. protozoan, Microregma	6		2.5 mg/l 183.0 mg/l				
B. Plants 1. Terrestrial	Indicator species can concentrate dangerously high levels of selenium.	77,38						No known indicator species are common in Illinois.
	Some crops species can also accumulate selenium in toxic amounts.	83,77			Large			Wheat, lettuce, cabbage, mustard, onion and most legumes.
2. Aquatic	Selenium can cause physiological & morphological changes in algae.	78		.079 mg/l (10^{-6}M)				Illinois vegetation is largely deficient in selenium.
3. Recreational	None							
4. Aesthetic & Human Interest	Probable opposition to deregulation of any chemical substance in water.							
5. Industrial/Commercial	None							
6. Agricultural	Highly seleniferous grains or pasture can cause livestock and poultry losses through death or infertility,	83						Does not apply in Illinois.
7. Structural	None							
8. Governmental	None							

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